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SCIENCE FOR
COALMINING STUDENTS

Science for Coalmining Students

BY

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FOREWORD

by C. McLUCKIE, Esq., M.I.Min.E., Dipl. R.T.C. (Glasgow),
C.C.M.

IN no branch of industry is it more important to have a constant flow of trained technicians into its ranks than in coal-mining. The improvements and developments in mining practice which have taken place in the past are all based on scientific principles and increase in scientific knowledge is followed by new developments. Consequently it is the trained mining engineer who will be called upon to apply scientific principles in these developments.

Not only the management but new entrants to the mining industry should have a knowledge of the elements of mining science to enable them to take an interest in the various phases of their work and particularly to increase the standards of safety and efficiency within the industry. In this connection an understanding of the physical and chemical laws relating to mine gases, the causes and prevention of explosions and the physiological effects of noxious gases on human beings is essential. Also the electrification of mines whereby the latest electrical machinery has been installed, the transmission of power and the economical use of electrical energy call for a thorough knowledge of electrical science.

"Science for Coalmining Students" deals with the basic principles underlying these subjects. The book, which is interesting, instructive and wide in scope, is the result of many years' experience in teaching science to mining students on the part of one of the authors and several years' practical experience underground by the other. Mining students have long felt the want of a textbook of science dealing with their own particular problems, particularly from the physical point of view. Consequently the book should prove very useful to candidates taking the various examinations for firemen, overmen and under-managers and to youths entering the industry.

C. McLUCKIE

*Hindley,
Nr. Wigan*

ELECTRICITY FOR COAL-MINING STUDENTS

by

J. STEVENSON, M.C., B.SC.,

and

W. MILLER, B.SC., Dipl. R.T.C.

This textbook aims at preparing mining students on Electricity for the Mines Department Examination and for Colliery Management Certificates of Competency.

239 pages

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PREFACE

THE object of this book is to provide a background of scientific knowledge upon which the practice of coalmining is based. The various processes which have to be carried out in order to transfer coal from the face to the consumer are based on the fundamental principles of Hydrostatics, Mechanics, Heat, Light, Electricity and Chemistry and in this book these principles are allied to their practical applications in mining.

The book is chiefly based on the syllabuses in Mining Science (Physics and Chemistry) for the examinations of the Union of Lancashire and Cheshire Institutes, the Union of Educational Institutions, the West Riding Education Department and similar bodies. But it also includes the greater portion of the basic groundwork in science for the more advanced papers in Mechanics, Heat Engines and Electricity of these examining bodies. The book should therefore be suitable for the Preliminary Mining Science examinations and should also be useful for the higher level examinations for firemen, overmen and undermanagers.

The authors extend their thanks to the past and present staff of the Mining Department of the Wigan and District Mining and Technical College and to Dr. H. Gregson, A.R.I.C., for several useful suggestions. Thanks are also due to the Union of Lancashire and Cheshire Institutes and the Union of Educational Institutions for permission to include questions from their examination papers.

H. MORTON
D. S. MORTON

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CHAPTER I

UNITS AND MEASUREMENTS

INTRODUCTION

Science to a large extent forms the basis of modern mining practice and many of its branches have been utilised in the various developments and improvements which have taken place in mining in recent years. In particular, the applications of fluid pressure, the elasticity of gases, the effects of heat on matter as regards expansion, change of state, etc., have been utilised in mining practice for a considerable number of years. So it is with the composition of mine air, the physiological effects of its constituent gases and the dangers due to explosions, all of which are questions depending on a knowledge of chemical science. In recent years, however, the electrification of mines whereby the latest electrical machinery has been installed, the transmission of power and the cost of electrical energy call for a thorough knowledge of electrical science.

It is with the scientific principles underlying these subjects that the following pages are about to deal.

MEASUREMENT OF LENGTH

Measurement of quantities such as length and mass is a very important part of science. To measure a certain distance, it is necessary to decide upon a unit and the distance is expressed as a definite number of these units. In the English system the unit of length is the yard, with subdivisions the foot and the inch. The unit of length in the metric system is the metre and the subdivisions of the metre are given below:

10 millimetres (mm.) = 1 centimetre (cm.)
10 centimetres (cm.) = 1 decimetre (dm.)
10 decimetres (dm.) = 1 metre (m.)
also 1 kilometre = 1,000 metres.

The Vernier

A standard scale is generally graduated in centimetres and tenths of a centimetre or in inches and tenths of an inch. If a length is required to one-hundredth of an inch or one-hundredth

of a centimetre, a vernier scale is used in conjunction with the standard scale. In Fig. 1, X and Y represent the standard and vernier scales respectively. It is arranged that 10 divisions of the vernier scale are equal to 9 divisions (e.g. tenths of an inch) of the standard scale. Thus one vernier division is equal to $\frac{9}{10}$ of a tenth of an inch.

If the length to be measured is 5.2 inches, together with the small element of length Hh , the length Hh can be found by noting where a division line of the vernier scale coincides with a division line of the standard scale, viz. Aa .

$$\begin{aligned}\text{Now distance } Bb &= \frac{1}{10} \text{ in.} - \frac{9}{10} \text{ of } \frac{1}{10} \text{ in.} \\ \text{and distance } Cc &= \frac{2}{10} \text{ in.} - \frac{9}{10} \text{ of } \frac{2}{10} \text{ in.} \\ \text{and finally distance } Hh &= \frac{7}{10} \text{ in.} - \frac{9}{10} \text{ of } \frac{7}{10} \text{ in.} \\ &= \frac{1}{10} \text{ of } \frac{7}{10} \text{ in.} \\ &= \frac{7}{100} \text{ in.} = 0.07 \text{ in.}\end{aligned}$$

Thus the length to be measured is 5.2 in. + 0.07 in., i.e. 5.27 inches.

Verniers are used for obtaining exact measurements in many scientific instruments used in mining, such as the vernier calipers, the scale of the Fortin barometer and the circular scale of the theodolite which measures angles to $\frac{1}{60}$ of a degree or one minute of arc.

VOLUME AND CAPACITY

Volume

The units of volume used in the English system are the cubic inch and the cubic foot. In the Continental system the units of volume are the cubic decimetre (i.e. the litre) and the cubic centimetre.

$$\begin{aligned}1 \text{ cubic decimetre (or 1 litre)} &= 10 \times 10 \times 10 \text{ cub. cm.} \\ &= 1,000 \text{ cub. cm.}\end{aligned}$$

Capacity

Capacity is the term which is applied to the internal volume of a vessel.

The Measuring Cylinder

The measuring cylinder (Fig. 2a) is an instrument which is used for measuring an exact volume of a liquid. The cylinder is generally graduated from the bottom upwards and is provided with a lip so that the liquid can be poured easily. When using a measuring cylinder, it is very important to have the eye level with the lowest part of the liquid surface (or meniscus as it is called). Fig. 2b shows how an incorrect reading may be

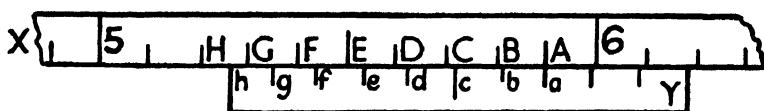


FIG. 1

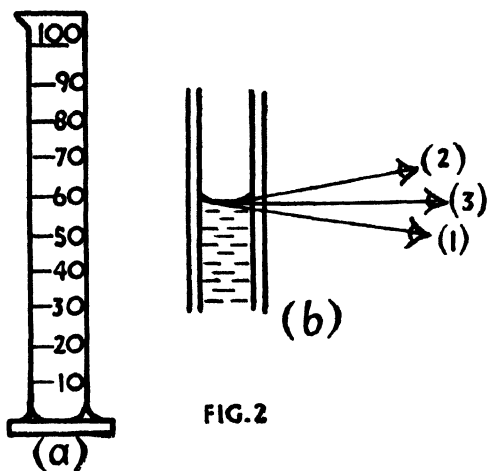


FIG. 2

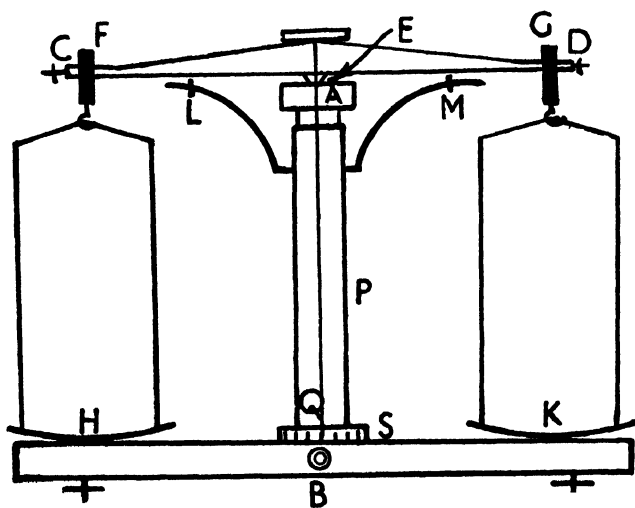


FIG. 3

made. If the eye is in the position (1) the reading is too small and if in position (2) the reading is too large. Position (3) gives the correct reading.

MASS AND WEIGHT

All matter, whether solid, liquid or gas, possesses mass. The mass of a substance is the quantity of matter contained in the substance and the weight of the substance is the force which pulls it towards the earth. The unit of mass in the English system is the Standard Pound, which is the quantity of matter in a piece of platinum, kept by the Board of Trade. In the metric system, the unit of mass is the Kilogram, which is the quantity of matter contained in a piece of platinum kept by the French Government.

Subdivisions of the pound are well known, while those of the kilogram are given in the following table :

10 milligrams (mgm.) = 1 centigram (cgm.)

10 centigrams (cgm.) = 1 decigram (dgm.)

10 decigrams (dgm.) = 1 gram (gm.)

1 kilogram = 1,000 grams.

also 1 kilogram = 2.2 lb.

The Common Balance

The common balance forms part of the equipment of a mining laboratory. In the balance shown in Fig. 3 the hollow pillar P is fixed to the base board which rests on levelling screws. A brass cylinder which supports an agate plane A can be moved up and down the hollow pillar by means of the handle B. The beam CD rests with its agate knife-edge E on the plane A. Knife-edges F and G, fixed to the beam, support hangers from which the pans H and K are suspended. When the balance is not in use the beam rests on the supports L and M, but when the handle is rotated clockwise, the agate plane A is raised and the beam swings freely. The free end of the pointer Q which is attached to the beam moves along the ivory scale S. The balance depends on the lever principle (see p. 50), for when the arms are of equal length the weights applied to their ends are also equal

Before weighing an object, the pointer must be opposite the zero of the scale when the beam is raised. The screws at C and D are adjusted so that this condition is observed.

A box of weights is shown in Fig. 4.

THE SPIRIT LEVEL.

A spirit level is shown in Fig. 5a. The glass tube PQYX, which is filled with alcohol except for a small bubble Z, is mounted in a metal framework ABCD, the upper surface PQ of the tube being arranged to be exactly parallel to the base BC. When the base BC is inclined to the horizontal the upper

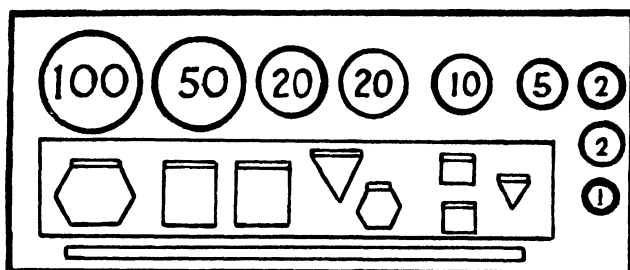


FIG. 4

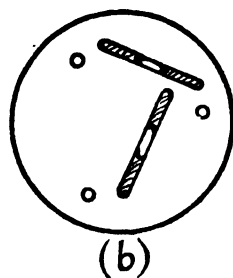
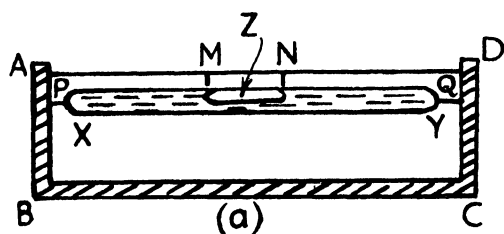


FIG. 5.

surface PQ is also inclined to the horizontal and the bubble rises to the highest part of the tube. When the bubble is in the centre of the tube, i.e. between the two marks M and N, the upper surface PQ is horizontal and consequently the base BC is also horizontal.

The spirit level forms an integral part of many instruments used in mine surveying, such as the theodolite, the dumpy level and the miner's dial. The theodolite is mounted on a

horizontal table which rests on three levelling screws, and two spirit levels, placed at right angles to each other, are used for making this adjustment. In order to level the table the screws are adjusted until each bubble is in the centre of the tube and the table becomes horizontal in every direction (Fig. 5b).

EXERCISES

1. Describe a screw gauge and explain how it may be used for finding the diameter of a wire.
2. Give the theory of a vernier which reads to one-hundredth of an inch.

CHAPTER II

HYDROSTATICS, A

DENSITY

The density of a substance may be defined as the weight of unit volume of the substance. If 20 c.c. of a sample of coal weigh 26 gm., the weight of 1 c.c. is 1.3 gm.; that is, the density of the coal is 1.3 gm. per c.c. Also in the English system of units, if 20 cub. in. of iron weigh 5.2 lb., the weight of 1 cub. in. is 0.26 lb. and the density of iron is 0.26 lb. per cub. in.

$$\text{Thus} \qquad \text{Density} = \frac{\text{Weight}}{\text{Volume}}$$

The following table gives the average densities of various types of coal and shale:

Substance	Density (gm. per c.c.)
Lignite	1.15
British bituminous coal	1.30
Anthracite	1.55
Ordinary shale	2.65
Oil shale	1.75

A litre of water weighs 1 kilogram, i.e. 1,000 c.c. of water weigh 1,000 grams and the density of water is 1 gm. per c.c.

Density is an important physical constant and it is often a criterion of the purity of a substance. In mining practice the process of coal washing depends on the fact that the impurities have greater densities than the coal and, if the impure coal is allowed to fall through water in large tanks, the impurities descend more rapidly than the coal. In this manner the materials form layers of equal density and can be separated, provided pulsating motion is given to the contents of the tank to help in the separation.

Another method of separation is to use a liquid of the same density as the coal. A suitable liquid is a solution of calcium chloride in water. If sufficient calcium chloride is dissolved in water a solution of the required density may be prepared.

When the solution is placed in the separating tank the coal, fully immersed, remains suspended near the surface of the solution (see p. 23) and the impurities sink to the bottom, again provided pulsating motion is given to the contents.

RELATIVE DENSITY

The relative density of a substance is the density of the substance compared with the density of water.

$$\text{Thus R.D. of substance} = \frac{\text{Wt. of 1 c.c. of substance}}{\text{Wt. of 1 c.c. of water}}$$

$$\text{i.e. R.D.} = \frac{\text{Weight of substance}}{\text{Weight of an equal volume of water}}$$

We may therefore define the relative density of a substance as the weight of the substance divided by the weight of an equal volume of water. Another name for relative density is specific gravity.

Determination of the Relative Density of a Liquid, e.g. Paraffin

The relative density of a liquid can be determined by means of a relative density or specific gravity bottle (Fig. 6). The bottle possesses a ground stopper which is in the form of a capillary tube with a very fine bore. If the bottle is filled with liquid nearly to the top of the neck and the stopper is inserted, the liquid emerges from the top of the tube and any excess can be removed. In this way exactly equal volumes of different liquids can be obtained.

To perform an experiment the bottle is first weighed empty and then weighed again filled with water. After emptying the water and rinsing out with a little paraffin, the bottle is filled with paraffin and weighed again. The results may be set out as follows:

Weight of bottle	= 25.75 gm.
Weight of bottle filled with water	= 75.78 gm.
Weight of bottle filled with paraffin	= 64.89 gm.
∴ Weight of water to fill the bottle	= 50.03 gm.
and Weight of paraffin to fill the bottle	= 39.14 gm.
Hence	R.D. of paraffin = $\frac{39.14 \text{ gm.}}{50.03 \text{ gm.}}$
	= 0.78.

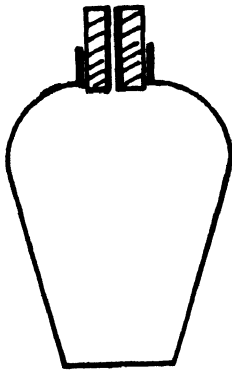
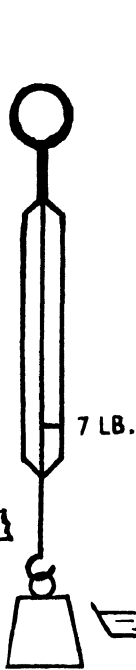
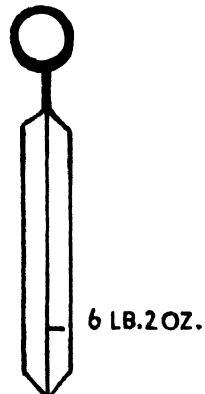


FIG. 6



7 LB.



6 LB. 2 OZ.

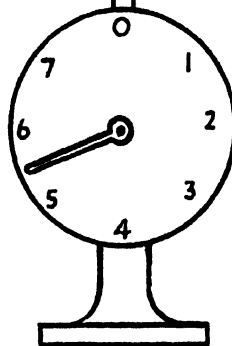
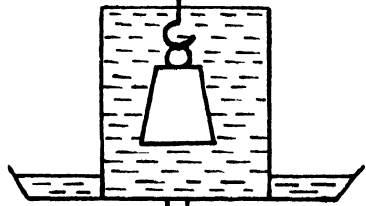


FIG. 7

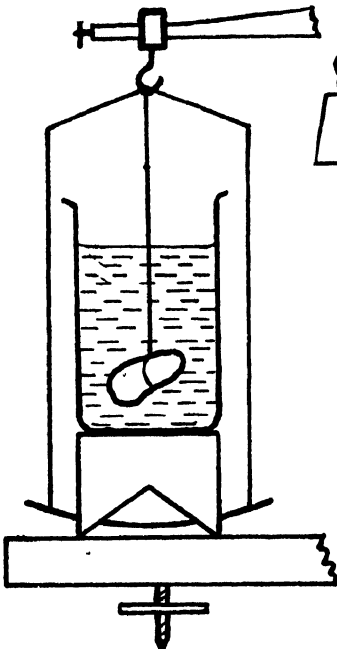


FIG. 8

ARCHIMEDES' PRINCIPLE

If a 7-lb. weight is suspended from a spring balance the indicator of the balance registers 7 lb. But if the 7-lb. weight is suspended, fully immersed in water, the indicator registers about 6 lb. Evidently there is an apparent loss of weight. Moreover the solid fully immersed in water displaces its own volume of the water. What is the connection between this apparent loss of weight of the solid and the weight of the liquid it displaces?

Fig. 7 shows a 7-lb. weight suspended from a spring balance. A large vessel, brimful with water, rests on a household scale pan. If the 7-lb. wt. is suspended, fully immersed, in the water and the vessel and contents are then removed from the pan, the water which has overflowed can be weighed. A set of results is shown below:

(1) Weight of solid in air	=7 lb.
Apparent wt. of solid in water	=6 lb. 2 oz.
Apparent loss in weight	=14 oz.
Weight of water displaced	=14 oz.
(2) Weight of solid in air	=4 lb.
Apparent wt. of solid in water	=3 lb. 8 oz.
Apparent loss of wt.	=8 oz.
Weight of water displaced	=8 oz.

Evidently the apparent loss of weight of the solid is equal to the weight of water displaced. If the experiment is repeated with a liquid such as paraffin, a similar conclusion will be reached. Thus Archimedes' Principle may be stated as follows: *If a solid is weighed in air and then in a liquid the apparent loss of weight of the solid or the upthrust of the liquid on the solid is equal to the weight of the liquid displaced.*

Determination of the Relative Density of a Solid by weighing in Air and in Water

If a solid (e.g. a piece of coal) is suspended by means of a piece of thread from one arm of a common balance, the weight of the solid in air may be determined. If the solid is then suspended freely in a beaker containing water which stands on a wooden bridge (Fig. 8), the apparent weight of the solid in water may also be determined. The relative density of the solid may then be calculated in the following manner:

Weight of solid in air	=25.72 gm.
Apparent weight of solid in water	= 5.93 gm.
Apparent loss of weight of solid in water	=19.79 gm.
Weight of water displaced	=19.79 gm.
Weight of an equal volume of water	=19.79 gm.
Relative density of solid	$=\frac{25.72 \text{ gm.}}{19.79 \text{ gm.}}$
	=1.30.

THRUST AND PRESSURE

If we consider a vessel with circular holes in its sides to be filled with water, the holes have to be closed by plugs to prevent the water from running out. The plugs stop the flow of the water and the water exerts a force or a thrust on each, whatever its position. If the plugs are withdrawn, water runs out of each hole as a jet. Each jet is horizontal as it leaves the vessel (Fig. 9) but eventually curves down towards the base. This shows that the thrust is everywhere at right angles to the surface of the vessel. Thus we see that a thrust is a force distributed over an area and that the thrust of a liquid on a surface is always at right angles to the surface.

Pressure

The pressure on a surface is the thrust per unit area of the surface, and the pressure is uniform when the thrust on each unit of area is the same.

Thus $P = \frac{F}{A},$

where F = the thrust in lb. wt.,

A = the area in sq. in.,

and P = the pressure in lb. wt. per sq. in.

Example. A thrust of 300 lb. is distributed uniformly over an area of 20 sq. in. Find the pressure.

$$P = \frac{F}{A}, \text{ where } F = 300 \text{ lb.}; A = 20 \text{ sq. in.}$$

$$\begin{aligned} \therefore P &= \frac{300 \text{ lb.}}{20 \text{ sq. in.}} \\ &= 15 \text{ lb. per sq. in.} \end{aligned}$$

Example. The pressure of steam in an engine cylinder is 100 lb.

per sq. in. Find the thrust on the piston, the area of which is 5.5 sq. in.

From $P = \frac{F}{A}$, we have $P = 100$ lb. per sq. in.; $A = 5.5$ sq. in.

$$\therefore 100 \left(\frac{\text{lb.}}{\text{sq. in.}} \right) = \frac{F}{5.5 \text{ sq. in.}}$$

$$\therefore F = 100 \left(\frac{\text{lb.}}{\text{sq. in.}} \right) \times 5.5 \text{ sq. in.} \\ = 550 \text{ lb.}$$

PRESSURE DUE TO A COLUMN OF LIQUID

It has already been seen that a liquid in a vessel exerts a thrust on each element of the surface and the thrust is everywhere at right angles to the surface. In the case of a cylindrical vessel, containing a quantity of liquid, the thrust on the base is clearly equal to the weight of the liquid column.

Thus we have:

$$\text{Pressure on the base} = \frac{\text{Weight of column}}{\text{Area of base}}$$

$$\text{i.e.} \quad P = \frac{\text{Volume} \times \text{Density}}{\text{Area of base}} \\ = \text{Height} \times \text{Density}$$

$$\text{i.e.} \quad P = hd,$$

where h , d and P are the height, density and pressure respectively.

Introducing units we have:

$$P \left(\frac{\text{gm.}}{\text{sq. cm.}} \right) = h \text{ (cm.)} \times d \left(\frac{\text{gm.}}{\text{cub. cm.}} \right)$$

$$\text{or} \quad P \left(\frac{\text{lb.}}{\text{sq. in.}} \right) = h \text{ (in.)} \times d \left(\frac{\text{lb.}}{\text{cub. in.}} \right)$$

Example. A vertical pipe runs in a shaft 100 yd. deep is completely filled with water. Find the pressure due to the column of water at the bottom of the range.

Density of water = 62.5 lb. per cub. ft.

$P = hd$, where h is the height in in., d is the density in lb. per cub. in. and P is the pressure in lb. per sq. in.

$$\therefore P = 100 \times 36 \text{ (in.)} \times \frac{62.5}{1728} \left(\frac{\text{lb.}}{\text{cub. in.}} \right) \\ = 130.2 \text{ lb. per sq. in.}$$

THE ATMOSPHERE

Surrounding the earth there is a gaseous covering known as the air or the atmosphere. Apart from any experimental

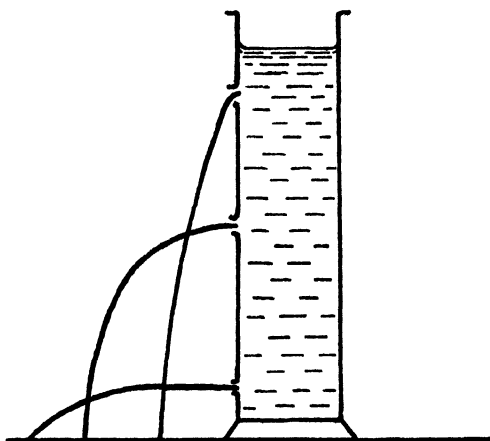


FIG. 9

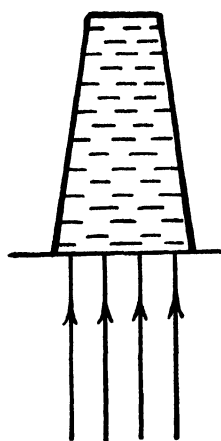


FIG. 10

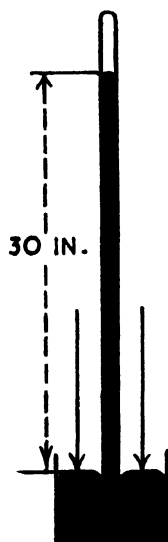


FIG. 11

evidence we are aware of its presence through winds, which are really air currents.

Since air is a form of matter it possesses mass, and the weight of a quantity of air is the force pulling the air towards the earth. This can be shown by pumping air into a sheet-metal cylinder, fitted with a bicycle valve. By weighing the cylinder and contents before and after the air is pumped in, an increase in weight is observed.

The Upward Pressure of the Atmosphere

If a tumbler is filled brimful with water and a sheet of stiff paper is held rigidly over the brim, when the tumbler is inverted and the hand removed, the sheet of paper appears to be supporting the column of water (Fig. 10). Actually it is the upward pressure of the atmosphere on the paper which keeps the water in the tumbler.

The Downward Pressure of the Atmosphere—the Mercurial Barometer

Fig. 11 shows a tube, $\frac{1}{4}$ in. bore, 36 in. long and closed at one end. The tube is filled with mercury and all the air bubbles are removed. If a finger is placed over the open end and the tube is inverted and supported with this end under the surface of mercury in a small dish, the mercury falls to a definite level, leaving a vacuum at the top of the tube. When the height of the mercury column above the level of mercury in the dish is measured, it is found to be approximately 30 inches or 76 cm. The downward pressure of the atmosphere on the mercury in the dish is transmitted through the mercury to the bottom of the tube. This pressure supports the mercury column.

The Fortin Barometer

A Fortin barometer, used on the surface of a mine, is shown in Fig. 12. Owing to the variations in the height of the mercury column, the level of the mercury in the cistern A must always be adjusted to be opposite the zero of the scale S_1 . The cistern possesses a rubber base and a screw S_2 adjusts the surface of the mercury to be in contact with the point of an ivory pin P which is opposite the zero of the scale. A vernier V, used in conjunction with the scale S_1 , enables readings to $\frac{1}{100}$ or $\frac{1}{200}$ in. to be accurately taken.

CALCULATION OF THE ATMOSPHERIC PRESSURE

1 cub. ft. of water weighs 62.5 lb.

∴ 1 cub. in. of water weighs $\frac{62.5}{1728}$ lb.

∴ 1 cub. in. of mercury weighs $\frac{62.5}{1728} \times 13.6$ lb., since the R.D. of mercury is 13.6.

Thus the atmospheric pressure

=the pressure due to 30 in. of mercury

=height \times density

$$= 30 \text{ (in.)} \times \frac{62.5}{1728} \times 13.6 \left(\frac{\text{lb.}}{\text{cub. in.}} \right)$$

=14.7 lb. per sq. in.

The Barograph

In mining practice records of the barometric pressure may be kept for future reference and a self-recording barometer or barograph which enables this to be done is shown in Fig. 13. The instrument consists essentially of an aneroid barometer and a revolving drum. The aneroid barometer A is a thin hollow corrugated metal box, partially exhausted of air and fixed rigidly to a base board. One end of a flat spring S is fixed to the top of the box and the other end is connected to an upright B. One end of a steel rod CD is also fixed to the upper face of the box and the other end of the rod is connected through a complicated system of levers (not shown in the diagram) to the end E of the stylo or lever EFG which is pivoted at F. The arrangement transmits and magnifies the motion of the top of the box to the end of the stylo which makes contact with the graph paper attached to the revolving drum H. The drum is rotated by clockwork and when there is no change in the atmospheric pressure a horizontal line is traced on the paper.

The box A responds to slight changes in the atmospheric pressure. When the pressure increases the top of the box is forced downwards and the end G of the stylo moves upwards. When the atmospheric pressure decreases the spring S raises the upper face of the box and the end G of the stylo is depressed. Thus the stylo traces out a graph, showing the atmospheric pressure at any particular instant.

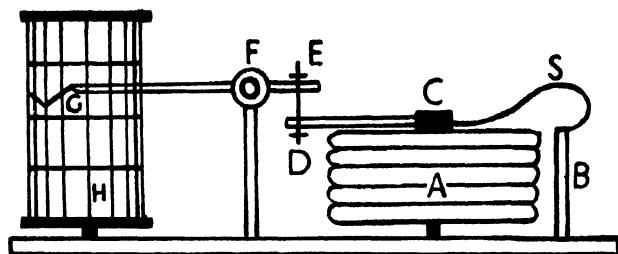


FIG. 13

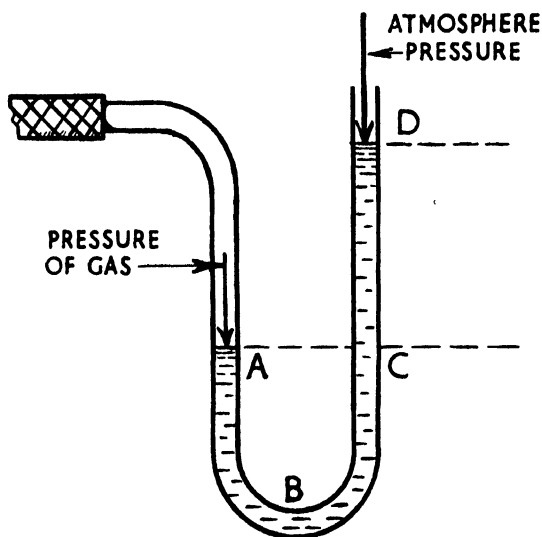
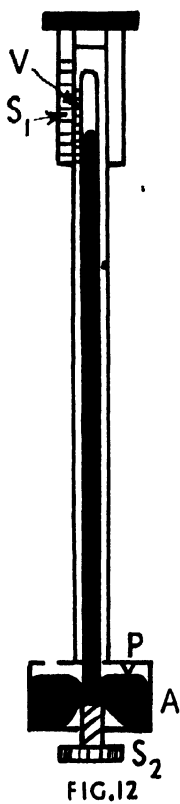


FIG. 14

PRESSURE DUE TO A COLUMN OF AIR

The pressure due to a column of air, e.g. the air in a mine shaft, can be calculated from the formula already established.

Example. Find the pressure due to a vertical column of air, 900 ft. high (a) in lb. per sq. in. and (b) in inches of mercury, if the mean density of the air is 0.079 lb. per cub. ft.

$$(a) \quad P = \rho h d$$

$$= 900 \text{ (ft.)} \times 0.079 \left(\frac{\text{lb.}}{\text{cub. ft.}} \right)$$

$$= 71.1 \text{ lb. per sq. ft.}$$

$$= \frac{71.1}{144} \text{ lb. per sq. in.}$$

$$= 0.494 \text{ lb. per sq. in.}$$

$$(b) \quad 14.7 \text{ lb. per sq. in.} = \text{pressure due to 30 in. of mercury.}$$

$$\therefore 0.494 \text{ lb. per sq. in.} = \text{pressure due to } 30 \times \frac{0.494}{14.7} \text{ in. of mercury.}$$

$$= \text{pressure due to 1.008 in. of mercury.}$$

From this example it can be seen that the height of the mercury column in a barometer increases by approximately 1 inch for every 900 feet down the shaft.

The Manometer and the Water Gauge

A manometer is an instrument which is used for measuring pressure. Fig. 14 shows a manometer containing a quantity of liquid and connected to the gas jet by means of rubber tubing. Before the gas is turned on, the liquid is at the same level in both branches of the tube. When the tap is opened, the liquid level in the right-hand branch rises and that in the left-hand branch falls. Considering the equilibrium of the liquid we have:

$$\text{Pressure of Gas} + \text{Pressure due to AB} = \text{Pressure due to CB} + \text{Pressure due to CD} + \text{Atmospheric Pressure}$$

But the pressure due to the column AB is equal to the pressure due to the column CB.

$$\text{Hence: } \text{Pressure of Gas in mains} = \text{Pressure due to column CD} + \text{Atmospheric Pressure}$$

Manometers or water gauges are used in the mine for finding the difference in pressure between the air in the upcast and down-cast shafts. The water gauge is placed on the separation door and a tube, fitted to one limb, protrudes through a hole in the door. The pressure of the air in the upcast shaft is reduced by the fan at the top and the difference of pressure between the

air in the two shafts, often referred to as the ventilation pressure, can be represented in inches of water.

We have:

$P=hd$, where h is the difference in level in inches and d is the density of water in lb. per cub. in.

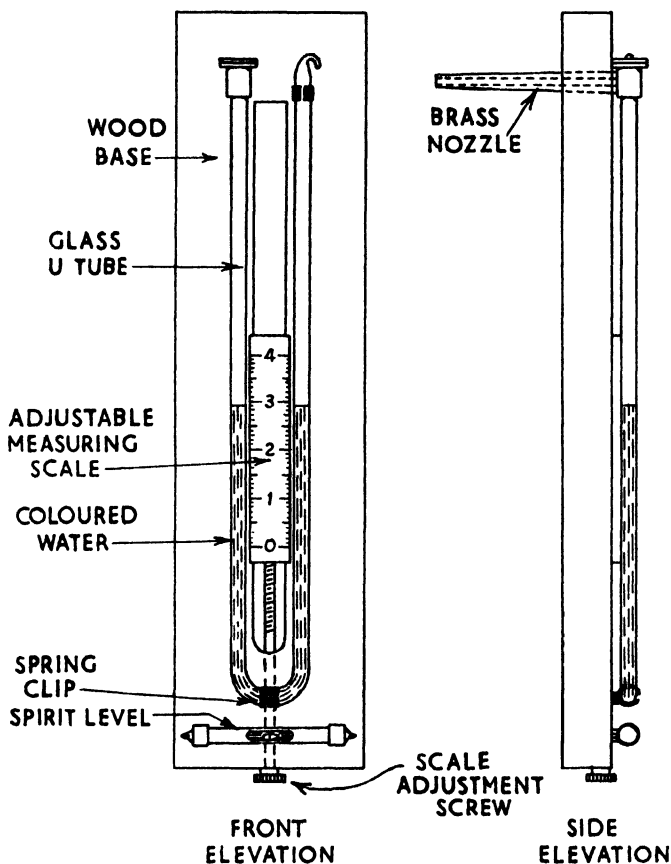


FIG. 15

Hence

$$P = h \times \frac{62.5}{1728}$$

$$= h \times 0.036.$$

Thus if $h=4.5$ in. of water, the difference of pressure is equal to 4.5×0.036 lb. per sq. in., i.e. 0.162 lb. per sq. in.

A water gauge used in practice is shown in Fig. 15.

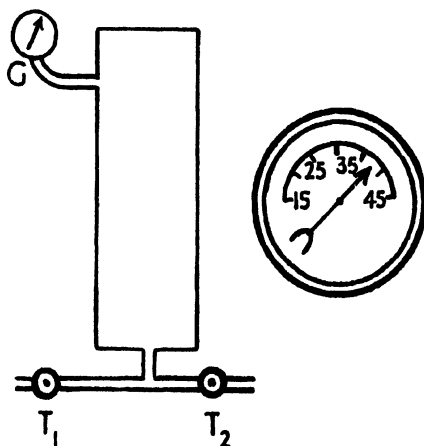


FIG. 16

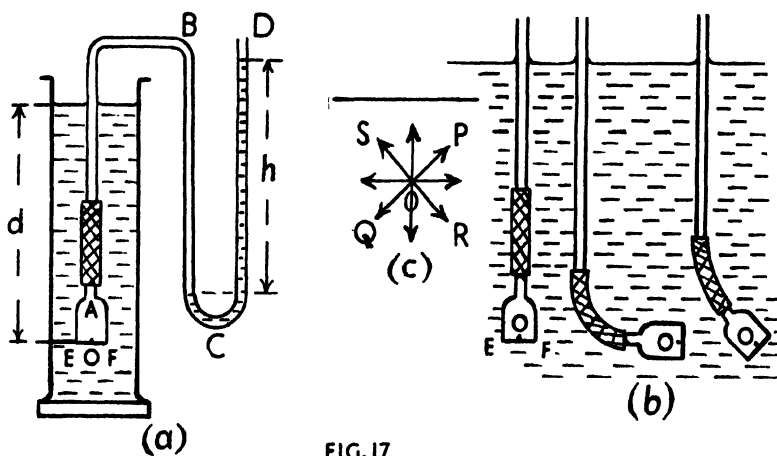


FIG. 17

ABSOLUTE PRESSURE

The absolute pressure of a gas is the pressure measured from zero or vacuum pressure. In the case of the gas in the mains we have:

$$\text{Absolute Pressure of Gas} = \text{Manometer Pressure} + \text{Atmospheric Pressure}$$

Fig. 16 shows a compressed-air receiver where T_1 is the inlet tap from the pump and T_2 , the exhaust tap. A Bourdon pressure gauge G indicates the absolute pressure of the air in the receiver. If the tap T_2 is opened, the pressure of the air in the receiver falls to atmospheric, viz. 14.7 lb. per sq. in., and the gauge G indicates this pressure. When the tap T_2 is closed and the tap T_1 is opened to the pump, the pressure of the air in the receiver may become 45 lb. per sq. in. absolute, for example, which is the sum of the atmospheric pressure and the excess pressure of the air pumped in.

Compressed air is used as the motive power in coal-cutting machines, conveyor-belt motors, drilling machines, etc., but the use of electrically driven machinery is increasing.

The Pressure at a Point in a Liquid is the same in all Directions

The bowl of a thistle funnel A is connected to a manometer BCD (Fig. 17a) which contains coloured water by means of a piece of rubber tubing. A thin membrane of rubber EF is fastened to the rim of the funnel by means of a piece of thin copper wire, so that the funnel is airtight. When the funnel is immersed in a cylinder containing water, so long as the centre O of the membrane is at the same depth d , the pressure indicated by the manometer is the same whatever the position of the funnel (Fig. 17b). The pressure of the water on EF is transmitted through the air to the liquid in the manometer and it can be seen that the pressure of the water at a point is the same in all directions. Thus, considering Fig. 17c, the pressure at O along OP is equal and opposite to the pressure along OQ and the pressure at O along OR is equal and opposite to the pressure along OS , etc.

The Pressure at a Depth in a Liquid

Consider a column of liquid $ABCDEFGH$ (Fig. 18) of uniform cross-sectional area, with the face $ABCD$ in the surface of the liquid and the face $EFGH$, at a depth h . The column of liquid is in equilibrium and the forces acting on it are:

- (1) the horizontal thrusts on the sides which balance one another, viz. the thrust P balances the thrust R and the thrust Q balances the thrust S ;
- (2) the weight of the column of liquid;
- (3) the upthrust on the base $EFGH$; and
- (4) the downward thrust of the atmosphere on $ABCD$.

Hence we have:

$$\text{Upward thrust on EFGH} = \text{Wt. of column of liquid} + \text{Downward thrust of atmosphere on ABCD}$$

$$\therefore \frac{\text{Upthrust on EFGH}}{\text{Area EFGH}} = \frac{\text{Volume of Column} \times \text{Density}}{\text{Area EFGH}} + \frac{\text{Downward thrust of atmosphere on ABCD}}{\text{Area EFGH}}$$

$$\therefore \text{Pressure at depth } h = \text{Depth} \times \text{Density} + \text{Downward pressure of atmosphere,}$$

since Area EFGH = Area ABCD.

Hence the difference between the pressures on EFGH and ABCD = Depth \times Density

i.e. $P = hd$.

PRACTICAL APPLICATIONS

In some mines flood water has to be arrested so as to prevent the flooding of the workings. This is effected by building dams of masonry or concrete to stop up the roadway affected. From the principles outlined above it can be seen that the pressure of the water is everywhere at right angles to the dam and also that the pressure increases uniformly with the depth of the water column. Thus the strength of the masonry at all parts of the dam must be sufficient to withstand the pressures arising from the varying heights of water column.

Another example of the tremendous pressures resulting from a considerable head of water is the action of underground spring water on the material which is used to fill up disused shafts. In Fig. 19, AB represents a disused shaft, filled in with material, and CD represents a roadway inclined to the horizontal XY and only filled in to a small distance on each side of the shaft. Water from underground springs collects in the portion CE of the disused roadway and when the pressure at E becomes great enough, the material is gradually washed away down the roadway FD. The material in the upper portion of the shaft sinks and a crater is left near the surface.

FLOATING SOLIDS

Fig. 20a shows a vessel, brimful with water and resting on a household scale. If a block of wood which has been previously weighed on the scale is allowed to float on the water (Fig. 20b), the water displaced overflows into the pan. If the vessel and

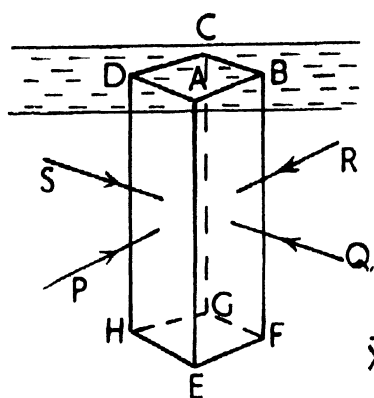


FIG. 18

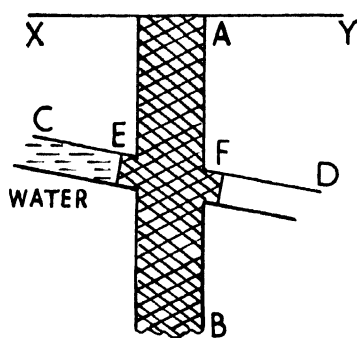
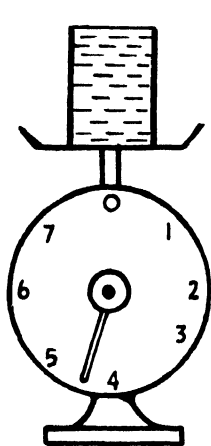
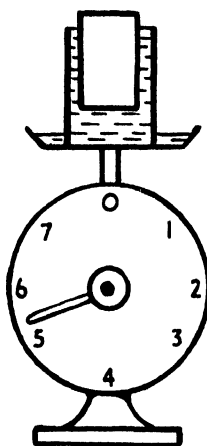


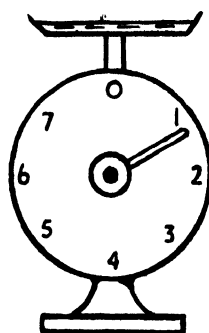
FIG. 19



(a)



(b)



(c)

FIG. 20

contents are removed, the weight of the displaced water will be indicated on the scale (Fig. 20c).

A set of results for three different experiments is shown below.

Weight of block $= 17$ oz.

Weight of water displaced (1) $= 16\frac{1}{2}$ oz.

Weight of water displaced (2) $= 17$ oz.

Weight of water displaced (3) $= 17\frac{1}{2}$ oz.

Thus the weight of the floating solid is approximately equal to the weight of water displaced. The same is true for paraffin or any other liquid in which the block floats, and if there is no experimental error we may state that:

Weight of floating solid = Weight of liquid displaced.

Relative Density of a Floating Rod of Uniform Cross-sectional Area

If we consider a rod of wood of uniform section (Fig. 21a) and L and l are the length of the rod and the length immersed respectively, we have:

Weight of rod = Weight of water displaced
 $=$ Weight of column EFCB of water

\therefore R.D. of rod

$$\begin{aligned}
 &= \frac{\text{Weight of rod}}{\text{Weight of an equal vol. of water}} \\
 &= \frac{\text{Weight of water displaced, viz. EBCF}}{\text{Weight of water equal in volume to rod, viz. ABCD}} \\
 &= \frac{l \times \text{area of section} \times \text{wt. of unit vol. of water}}{L \times \text{area of section} \times \text{wt. of unit vol. of water}} \\
 &= \frac{l}{L} = \frac{\text{Length immersed}}{\text{Total length}}
 \end{aligned}$$

The Hydrometer

If we consider a solid floating first in a dense liquid and then in a liquid of smaller density, the weight of the liquid displaced in each case is the same, being equal to the weight of the solid. Hence the volume of the denser liquid displaced is less than that of the liquid of smaller density and the solid sinks deeper in the latter liquid. The hydrometer (Fig. 21b) is constructed on this principle. A bulb A is provided with a tube CD which is closed at the end D. A smaller bulb B, containing a quantity of mercury, keeps the hydrometer in an upright position. The

tube CD is graduated from 1,000 to 1,200. When the hydrometer is placed in water it sinks to the mark 1,000, but when placed in sulphuric acid of relative density 1.2, it sinks to the

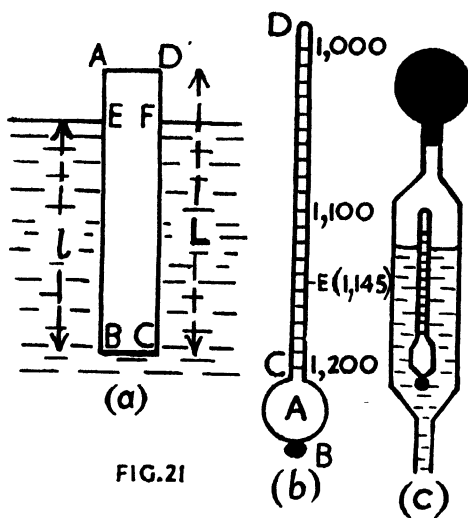


FIG. 21

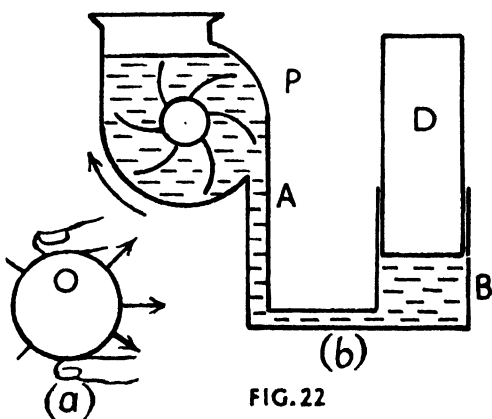


FIG. 22

mark 1,200. If the instrument sinks to the mark E 1,145 in a further liquid, the relative density of this liquid is 1.145.

The density of sulphuric acid is a criterion as to whether an accumulator requires recharging. Acid is withdrawn from the accumulator by means of the arrangement shown in Fig. 21c and a small hydrometer registers its density.

One of the methods for finding the density of coal is to prepare a solution of calcium chloride of greater specific gravity than the coal. When the sample of coal is placed in the vessel, it floats on the surface of the solution. On adding water and stirring the solution becomes less dense and the coal just becomes immersed with its upper surface in the surface of the liquid. In this case the solution and the coal have the same specific gravity which can be determined by a suitable hydrometer.

THE TRANSMISSIBILITY OF FLUID PRESSURE

Fig. 22a shows a hollow rubber ball, perforated with small holes and filled with water through the opening O. If the thumb is placed over the opening and the ball squeezed, the water issues from the holes in jets. This shows that the pressure applied to the ball is transmitted to the water near the holes.

The Hydraulic Jack

The transmissibility of fluid pressure is utilised in the hydraulic jacks which are components of the Joy loader, a machine used for loading coal or rock on to conveyors. A centrifugal oil pump P (Fig. 22b) puts the oil in the tube A under pressure. This pressure is transmitted to the oil in the cylinder B of the jack and the plunger D is forced upwards with a considerable force.

Example. If the thrust in the tube A, developed by the centrifugal pump, is 60 lb. wt. and the diameters of the cylinders A and B are 1 in. and 5 in. respectively, find the upward thrust on the plunger D (Fig. 22b).

$$\text{Fluid pressure in tube A} = \frac{60}{\pi \times (0.5)^2} \text{ lb. per sq. in.}$$

$$\therefore \text{Fluid pressure in tube B} = \frac{60}{\pi \times (0.5)^2} \text{ lb. per sq. in.}$$

$$\begin{aligned} \therefore \text{Thrust on plunger D} &= \frac{60}{\pi \times (0.5)^2} \times \pi \times (2.5)^2 \text{ lb. wt.} \\ &= 1,500 \text{ lb. wt.} \end{aligned}$$

EXERCISES

1. Define the following terms: (a) specific gravity, (b) density. Describe how you would determine the density of air and the specific gravity of a piece of coal. (Min. Sc.; U.L.C.I.)

2. What is meant by the Principle of Archimedes? Sketch, and describe, a hydrometer such as may be used to find the specific gravity of the acid solution in an electric accumulator or battery. Show clearly how the instrument is graduated. (Min. Sc.; U.L.C.I.)

3. One end of a U-tube containing water is connected to a gas supply, and the difference in level of the liquid in each limb of the tube is 5.45 in. Calculate the pressure of the gas supply in lb. per sq. in. (The weight of 1 cu. ft. of water is 62.5 lb.) What would be the reading on the gauge if it contained a liquid whose density was 50 lb. per cu. ft.?

(Min. Sc.; U.L.C.I.)

4. Describe the mercury barometer, explain how it works and state the purpose for which it is used in mines.

(Min. Sc.; U.L.C.I.)

5. Describe how you would determine the specific gravity of a piece of coal.

A piece of sandstone weighs 2.75 lb. in air and 1.75 lb. when submerged in water. What is its specific gravity?

(Min. Sc.; U.L.C.I.)

6. Describe fully how you would construct a simple mercury barometer. Given that the specific gravity of mercury is 13.6, describe how the pressure of the atmosphere may be directly determined.

(Min. Sc.; U.L.C.I.)

7. Describe two simple experiments to show that the atmosphere exerts pressure. Explain how, and why, atmospheric pressure may be measured by means of a mercury barometer.

(Min. Sc.; U.L.C.I.)

8. (a) What will be the pressure in lb. per sq. in. at the base of a column of water pipes in a mine shaft 630 yd. deep?

(b) The water gauge reading at a colliery is 6.6 in. What is the difference in pressure in lb. per sq. in. between the air in the fan drift and the outside atmosphere? (1 cu. ft. of water weighs 62.5 lb.)

(Min. Sc.; U.L.C.I.)

9. State Archimedes' Principle.

A large piece of coal weighs 12 lb. 8 oz. in air. When suspended in water it weighs 2 lb. 14 oz. Find the specific gravity of the coal.

(Min. Sc.; U.E.I.)

10. Explain the action of an aneroid barometer. An aneroid barometer indicates pressures of 14.7 lb. per sq. in. and 15.1 lb. per sq. in. at the top and at the bottom of a mine shaft respectively. What is the depth of the shaft? (Density of air = 0.079 lb. per cu. ft.)

(Min. Sc.; U.L.C.I.)

11. The height of the mercury column in a barometer at the top of a shaft, 400 yd. deep, is 29.8 in. What is the height of the mercury column in a barometer at the bottom of the shaft? (Mean density of the air in the shaft = 0.079 lb. per cu. ft.; density of mercury = 0.49 lb. per cu. in.)

(Min. Sc.; U.L.C.I.)

12. Describe, and explain, the use of (a) a water gauge, and (b) a hydrometer. Draw a diagram in each case.

(Min. Sc.; U.L.C.I.)

13. What is meant by the term "specific gravity"? A sample of coal weighs 120.75 gm. If the apparent weight of the sample when suspended in water is 29.47 gm., what is its specific gravity?

(Min. Sc.; U.L.C.I.)

14. Describe a water gauge and explain its use.

A water gauge is fitted on the door leading into a fan drift. The level of the water is 5.3 in. higher in the limb connected to the drift than in the other. If the atmospheric pressure is 14.70 lb. per sq. in., what is the pressure of the air in the fan drift? (1 cu. ft. of water weighs 62.5 lb.)

(Min. Sc.; U.L.C.I.)

15. The density of air at the top of a mine shaft where the barometer reads 30 in. of mercury is 0.079 lb. per cu. ft. What is the density of the air at the bottom of the shaft where the barometer reads 30.4 in.? Assume the temperature to be the same in each case.

(Min. Sc.; U.L.C.I.)

16. Describe the construction of a mercury barometer. If the height of the mercury is 29.5 in., what is the pressure of the atmosphere? (Mercury weighs 0.49 lb. per cu. in.)

(Min. Sc.; U.L.C.I.)

17. Define (a) density, and (b) specific gravity.

A specific gravity bottle weighs 20.76 gm. empty. When the bottle is filled with water it weighs 50.72 gm. and when filled with mercury it weighs 128.20 gm. What is the specific gravity of mercury?

(Min. Sc.; U.L.C.I.)

18. A barometer indicates a pressure of 29.5 in. of mercury at the top of a mine shaft and 31.1 in. at the bottom. What is the depth of the shaft? (Density of mercury = 0.49 lb. per cu. in, density of air in the shaft = 0.079 lb. per cu. ft.)

(Min. Sc.; U.L.C.I.)

19. Describe a water gauge and explain its use. The difference in level between the water surfaces in a water gauge is 6.4 in. What difference of pressure in pounds per square foot does this reading represent? (1 cu. ft. of water weighs 62.5 lb.)

(Min. Sc.; U.E.I.)

20. What is meant by the terms (a) density, and (b) specific gravity?

What is the volume of 2.5 tons of water if the density of water is 62.5 lb. per cu. ft.?

(Min. Sc.; U.E.I.)

CHAPTER III

HYDROSTATICS, B

BOYLE'S LAW

The Investigation of the Relationship between the Volume and the Pressure of a given Mass of Air at Constant Temperature

Fig. 23 shows an apparatus which is used for finding the relationship between the volume and the pressure of a given mass of air at constant temperature. The apparatus consists of a glass tube AB of $\frac{3}{8}$ in. bore and mounted on a wooden stand. The tube is closed at the end A and the end B is connected by pressure tubing C to the reservoir D which is fixed to a wooden slider E. This slider moves along a slot in the stand and is kept in position by a wing nut at the back. The reservoir, pressure tubing and a portion of the tube AB contain mercury and a quantity of air is trapped in the tube AB. The pressure of this air is given by:

$$P = B + h,$$

where B = the barometric pressure in inches of mercury,

h = the excess pressure in inches of mercury,

and P = the absolute pressure of the enclosed air in inches of mercury.

To perform an experiment, the length of the air column AX and the excess pressure XY are measured by means of the scale F, attached to the apparatus. The barometric height is observed and the absolute pressure of the air in AB is calculated. When the reservoir is moved into another position the length of the air column and the excess pressure are again read and so on. A set of results is shown below (barometric height $B = 29.8$ inches of mercury):

Length AX (l inches of mercury)	Excess Pressure (h inches of mercury)	Absolute Pressure $P = B + h$ inches	Pl
18.5	5.0	34.8	643.8
16.3	9.6	39.4	642.2
14.4	14.8	44.6	642.2
12.6	21.3	51.1	643.9
10.9	29.2	59.0	643.1

These results show that the product Pl is approximately constant. But the volume V of trapped air is proportional to the length l .

Hence PV is a constant,
or V varies inversely as P .

The temperature of the enclosed air remains practically constant during the experiment.

The results of the above experiment verify Boyle's Law, which may be stated as follows: *The volume of a given mass of a gas varies inversely as its pressure if the temperature remains constant.*

Example. If 1,000 cub. ft. of air at a pressure of 15 lb. per sq. in. are compressed to a volume of 200 cub. ft. what is the final pressure of the air, assuming constant temperature?

$$\begin{aligned} \text{From} \quad & PV = C, \text{ where } C \text{ is a constant,} \\ \text{we have} \quad & P = 15 \text{ lb. per sq. in.} \\ & V = 1,000 \text{ cub. ft.} \\ \therefore & 15 \times 1,000 = C \\ \text{i.e.} \quad & PV = 15 \times 1,000. \\ \text{Now put} \quad & V = 200 \text{ cub. ft.} \\ \therefore & P \times 200 = 1,000 \times 15. \\ \therefore & P = \frac{1,000 \times 15}{200} \\ & = 75 \text{ lb. per sq. in.} \end{aligned}$$

Example. A compressed-air receiver contains 200 cub. ft. of air at a pressure of 60 lb. per sq. in. Air is allowed to escape until the pressure becomes 40 lb. per sq. in. What volume will the air which escapes occupy at atmospheric pressure, viz. 15 lb. per sq. in.? Assume temperature constant.

Initial pressure \times Initial volume = Final pressure \times Final volume.

$$\begin{aligned} & 60 \left(\frac{\text{lb.}}{\text{sq. in.}} \right) \times 200 \text{ (cub. ft.)} = 40 \left(\frac{\text{lb.}}{\text{sq. in.}} \right) \times V. \\ \therefore & V = \frac{200 \times 60}{40} \text{ cub. ft.} \\ & = 300 \text{ cub. ft.} \end{aligned}$$

Thus 100 cub. ft. of air at 40 lb. per sq. in. pressure escape.
Again:

Initial pressure \times Initial volume = Final pressure \times Final volume.

$$\begin{aligned} \therefore & 40 \left(\frac{\text{lb.}}{\text{sq. in.}} \right) \times 100 \text{ (cub. ft.)} = 15 \left(\frac{\text{lb.}}{\text{sq. in.}} \right) \times V. \\ \therefore & V = \frac{40 \times 100}{15} \text{ cub. ft.} \\ & = 266.7 \text{ cub. ft.} \end{aligned}$$

Practical Applications of Boyle's Law and Barometric Readings in Mining

The reading of the barometer at frequent intervals is very important in mining practice. Colliery officials are enabled to ascertain the condition of underground workings with regard to the emission of gases from the strata, the gobs and the cavities. When the atmospheric pressure is decreasing, the pressure of these gases in the cavities, gobs, etc., falls with a consequent increase in volume. The gases spread out into the workings and the ventilation may require adjustment to counteract this danger. If, on the other hand, the pressure of the atmosphere is increasing, the gases are kept confined to the strata, cavities, etc., and danger from escaping gases is at a minimum.

THE WATER BAROMETER

Example. What is the height of a column of water which will exert the same pressure as a column of mercury 30 inches high? R.D. of mercury = 13.6.

Let h = height of the water column in inches. Pressure of the atmosphere = $h \times \text{density of water}$, and pressure of the atmosphere = $30 \times \text{density of mercury}$.

$$\therefore h \times \text{density of water} = 30 \times \text{density of mercury.}$$

$$\therefore h = 30 \text{ (in.)} \times \frac{\text{density of mercury}}{\text{density of water}}$$

$$= 30 \text{ (in.)} \times 13.6.$$

$$= 408 \text{ in.}$$

$$= 34 \text{ ft.}$$

Thus the height of the water barometer is 34 feet.

PUMPS

The Lift Pump

Fig. 24a shows a model of a lift pump. A is the pipe, the lower end of which is immersed in water and B is the barrel in which the piston P moves. The piston P is connected by means of a rod to the end G of the handle GH which is pivoted at F. A ball valve V_1 rests in a socket at the top of the pipe and a valve V_2 closes a circular hole in the piston.

Suppose the piston is at the bottom of the barrel. When the piston is raised, a partial vacuum is created in the barrel and the pressure of the atmosphere closes the valve V_2 . Air and water rise up the pipe A, through the valve V_1 and into the barrel. When the piston is depressed the pressure above the valve V_1 becomes greater than that below and the valve closes. Also the valve V_2 opens, allowing water to rise through the

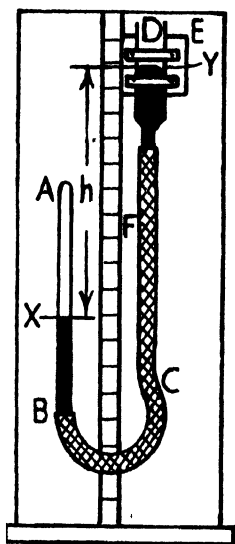


FIG. 23

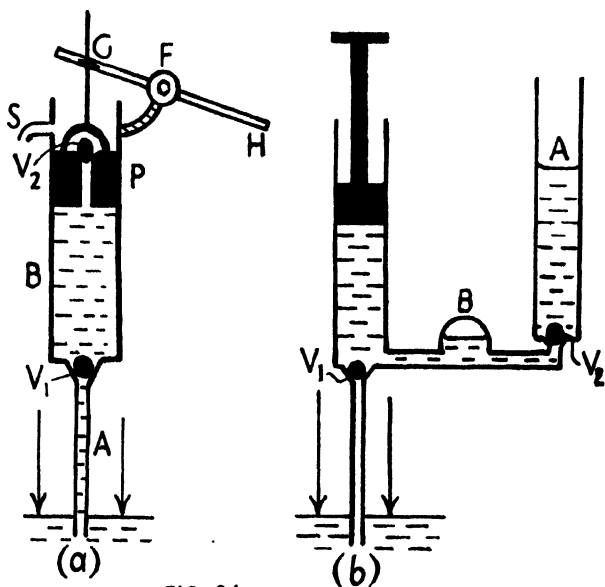
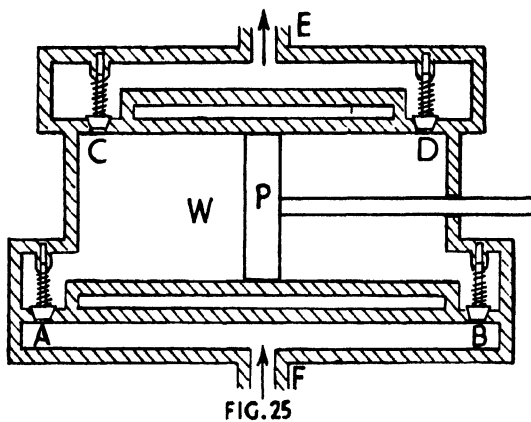


FIG. 24

piston. A succession of upward and downward strokes delivers the water from the spout S.

In practice, owing to leakage of air past the piston, water cannot be raised 34 feet as would be expected from the previous theory. The height in actual practice is no more than 28 feet.

The Force Pump

In this type of pump (Fig. 24b) water is raised into the barrel during the upward stroke of the piston. Then, on the downward stroke, the valve V_1 closes, preventing the water from running back to the pipe. The water is forced along the horizontal tube, through the valve V_2 and up the delivery pipe A. During the next upward stroke of the piston, more water passes up the pipe and through the valve V_1 , but the valve V_2 closes, preventing the water in the delivery tube from running back into the barrel. The air in the vessel B acts as a cushion by preventing sudden changes of pressure and in this way the water is delivered continuously. With this pump water can be forced to any height consistent with the force applied to the pump handle.

The Reciprocating Pump

A reciprocating pump used in mining operations is shown in Fig. 25. As the piston P moves to the left, the valve A is closed and the valve B opens, allowing water from the pipe F to enter the cylinder W to the right of the piston. During this operation the water already on the left of the piston is forced through the valve C and up the delivery pipe E, the valve D being kept closed by the pressure of the water above it.

As the piston moves to the right, the valve B closes and the valve A opens, allowing water to enter the cylinder to the left of the piston. At the same time the water already to the right of P is forced past the valve D and up the delivery pipe E, the valve C being kept closed by the pressure of the water above it.

THE SIPHON

A simple siphon tube is shown in Fig. 26a. A tube DC, bent twice at right angles, is placed with one end in a cylinder containing water. By applying the mouth to the end C, water can be drawn through the tube. The water continues to flow out of the tube until the level of the water in the cylinder is opposite the end C. Then the water ceases to flow.

To explain this siphon effect it is necessary to remember that the pressure along the horizontal line XY is everywhere the same and equal to the downward pressure of the atmosphere on the water surface in the cylinder. Thus the pressures inside the tube at A and B are each equal to the atmospheric pressure. But the downward pressure of the water at C is greater than the pressure at B, i.e. greater than the atmospheric pressure. Thus at C we have the upward pressure of the atmosphere and the downward pressure of the water which is greater than atmospheric pressure. Consequently the water runs out of the tube.

The siphon principle is applied in practice in a variety of processes, chiefly in the emptying of tanks which are in inaccessible places. It is also used for emptying sump holes containing water in mining operations. Fig. 26b shows a siphon tube ABC with a non-return valve at A, a priming tap at B and a discharge tap at C. With A and C closed, the tube is filled with water through the priming tap B. This tap is now closed and the tap C is opened. Water is thus siphoned over from the sump hole to the lower level. The figure shows a special perforated entrance tube D which prevents solid matter from entering the tube.

THE CENTRIFUGAL FAN

If a small solid is attached to a piece of thin string and the free end of the string is held in the hand, when the solid is whirled round in a circle, the tension of the string becomes considerable. If the speed of the solid is gradually increased, the tension of the string increases, the string ultimately breaks and the solid flies off at a tangent. The force acting from the centre of the circle along the string which breaks or tends to break it, is known as the centrifugal force.

This is one of the principles involved in the action of the centrifugal fan shown in Fig. 27. W is the impeller wheel, fitted with blades. When the wheel is rotated by an electric motor at the side of the casing C, air is thrown off the blades tangentially and forced through the opening O. Air is drawn through the eye E to neutralise the vacuum which tends to be created.

Fans are used extensively in mining for ventilation purposes. Air is drawn up one shaft by a fan, placed on the surface and connected to the shaft by means of a drift, and a strong current of air descends the other shaft. In this manner, by forced convection (see p. 112), a continuous supply of fresh air is circulated through the workings.

THE ANEMOMETER

The anemometer (Fig. 28) is an instrument used for measuring the velocity of air currents in underground roadways. The instrument consists of a set of vanes G, mounted on a hub and surrounded by a guard ring which protects the vanes from damage. The movement of the vanes is transmitted by means of shafting and gears to pointers which move along three circular scales in a metallic housing. The housing is provided with a glass cover and is rigidly fixed to a metallic base by four supports.

The movement of the pointers is controlled by a lever L which permits rotation of the vanes with or without the movement of the pointers.

The instrument actually measures the length of the air column (in feet) passing through the vanes and the three scales already mentioned indicate measurements in feet, hundreds of feet, and thousands of feet respectively.

When used in conjunction with a stop watch the time taken for a certain column of air to flow may be ascertained and subsequently the velocity of air flow may be calculated. If the measurement is taken exactly over one minute the anemometer reading then gives the velocity of air flow in feet per minute directly.

Measurement of Quantity of Air flowing per Minute

If the cross-sectional area of the roadway transverse to the direction of the air flow is measured at the same place as the anemometer reading is taken, then the quantity of air flowing past this position per unit time can easily be calculated.

Example. The velocity of air flow at a point in an underground roadway is 3,000 ft. per minute. If the cross-sectional area of the roadway is 30 sq. ft., find the quantity of air flowing through the roadway per minute.

$$\begin{aligned}\text{Quantity of air flowing} &= 3,000 \text{ ft./min.} \times 30 \text{ sq. ft.} \\ &= 90,000 \text{ cub. ft. per min.}\end{aligned}$$

EXERCISES

1. Explain how a simple ram or force pump operates. What factors determine the depth from which a pump will draw water to its own level? (Min. Sc.; U.L.C.I.)
2. How does the ventilation of the workings of a mine exemplify (a) Boyle's Law, and (b) Graham's Law? (Min. Sc.; U.L.C.I.)
3. In connection with the ventilation of a mine, explain the use and

principles of action of the anemometer and the water gauge. What is recorded by the anemometer? (Min. Sc.; U.L.C.I.)

4. Describe, in detail, how air currents in mines are measured and how the quantity of air passing through an airway is calculated. (Min. Sc.; U.L.C.I.)

5. State Boyle's Law. What volume of air originally at 60 lb. per sq. in. absolute would occupy 1,000 cub. ft. when expanded to a pressure of 14.4 lb. per sq. in. absolute? (Min. Sc.; U.L.C.I.)

6. State Boyle's Law. A compressed air receiver contains 55 cub. ft. of air at an absolute pressure of 80 lb. per sq. in. Assuming the temperature to remain constant, what volume would this quantity of air occupy at atmospheric pressure, which is 14.7 lb. per sq. in.? (Min. Sc.; U.L.C.I.)

7. Describe, and explain, the action of a pump of the reciprocating type. Draw a diagram to illustrate your answer. If the pressure of the atmosphere is 14.7 lb. per sq. in., what is the theoretical depth from which the pump can draw its water? (1 cub. ft. of water weighs 62.5 lb.) (Min. Sc.; U.L.C.I.)

8. State Boyle's Law. A compressed air receiver has a volume of 200 cub. ft. and contains air at an absolute pressure of 30 lb. per sq. in. If 600 cub. ft. of air at atmospheric pressure (viz. 15 lb. per sq. in.) are pumped in, what is now the pressure of the air in the receiver? Assume the temperature to remain constant. (Min. Sc.; U.L.C.I.)

9. Give a diagram of an anemometer. For what purpose is it used in mining?

Find the quantity of air in cub. ft. per minute which flows past a fixed station in an underground roadway of rectangular section, 12 ft. by 9 ft., if the velocity of the air when measured at this station is 500 ft. per minute. (Min. Sc.; U.E.I.)

10. Give a diagram of a fan and explain its use in mining. (Min. Sc.; U.E.I.)

11. A quantity of gas is maintained at constant temperature. What is the effect on the volume of the gas of (a) a reduction of pressure and (b) an increase of pressure?

How may the composition of mine air be affected by a reduction of the atmospheric pressure? (Min. Sc.; U.E.I.)

CHAPTER IV

DIFFUSION

DIFFUSION IN LIQUIDS

Fig. 29 shows a flat cork on the surface of a solution of copper sulphate in a gas jar. When water is gently poured upon the cork, the water forms as a distinct layer on the solution with a definite line of demarcation between them and the cork floats on the surface of the water. The function of the cork is to allow the water to be poured upon the solution without risk of mixing. When the cork is removed and the jar is left for a few weeks it will be found that the line of demarcation has disappeared and the liquids have mixed. A number of heavy particles of copper sulphate solution have risen in the jar and a number of lighter particles of water have descended to take their places. This process is known as diffusion.

DIFFUSION OF GASES

Diffusion also takes place when two gases are placed in contact with each other. Although the heavier gas may be below the lighter one, molecules of the heavy gas diffuse upwards and molecules of the lighter gas diffuse downwards.

If a porous pot A is fitted with a rubber stopper, through which one end of a glass U-tube is inserted (Fig. 30a), and a quantity of coloured water is poured into the U-tube, after a time the levels in the two branches become the same. If an inverted beaker D is placed over the pot and coal gas is led from the jet into the beaker, the water level descends to B in one branch and ascends to C in the other. This shows that the molecules of coal gas pass through the pores of the pot at a greater rate than the molecules of air pass from the pot into the beaker. Thus the molecules of coal gas, a lighter gas than air, diffuse through the pores more quickly than the molecules of air.

Fig. 30b shows a similar apparatus with the porous pot A enclosed in an upright beaker containing carbon dioxide. The water level ascends to B in the left-hand branch and descends to C in the right-hand branch. This shows that molecules of air diffuse through the pores of the pot at a greater rate than molecules of carbon dioxide.

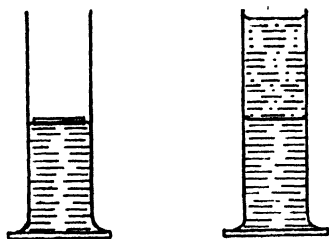


FIG. 29

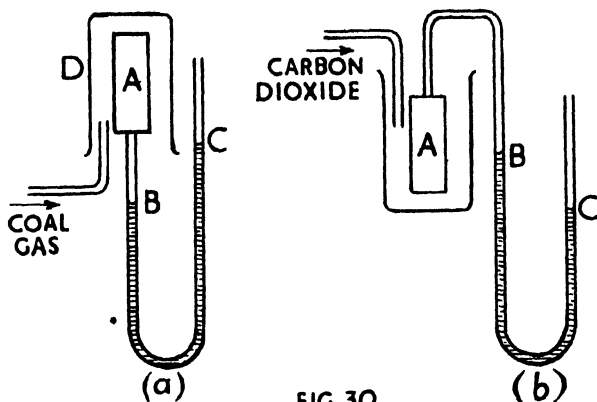


FIG. 30

GRAHAM'S LAW OF DIFFUSION

Graham's Law of Diffusion states that *gases diffuse at rates which are inversely proportional to the square roots of their densities*. Expressing this law by means of a formula, we have:

$$\frac{\text{Rate of diffusion of gas 1}}{\text{Rate of diffusion of gas 2}} = \frac{\sqrt{\text{density of gas 2}}}{\sqrt{\text{density of gas 1}}}$$

Taking methane and air as an example, since the densities of methane and air are in the ratio 0.555 to 1, we have:

$$\frac{\text{Rate of diffusion of methane}}{\text{Rate of diffusion of air}} = \frac{\sqrt{1}}{\sqrt{0.555}} = 1.34 \quad (1)$$

Again, taking the case of carbon dioxide and air, the densities of carbon dioxide and air are in the ratio of 1.528 to 1.

Hence

$$\frac{\text{Rate of diffusion of carbon dioxide}}{\text{Rate of diffusion of air}} = \frac{\sqrt{1}}{\sqrt{1.528}} = 0.81 \quad (2)$$

From (1) the rate of diffusion of methane

$$= 1.34 \times \text{rate of diffusion of air}$$

and from (2) the rate of diffusion of carbon dioxide

$$= 0.81 \times \text{rate of diffusion of air}$$

Hence

$$\frac{\text{Rate of diffusion of methane}}{\text{Rate of diffusion of carbon dioxide}} = \frac{1.34}{0.81} = 1.65 \text{ (approx.)} \quad (3)$$

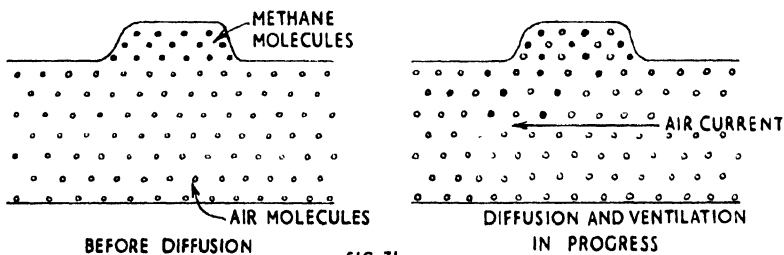


FIG. 31

PRACTICAL APPLICATIONS IN MINING

The phenomenon of diffusion is important from the point of view of the miner. Methane, which is a constituent of firedamp, is lighter than air and collects in the wastes and gobs near the roof and in the rise workings. The process of diffusion causes the methane, although lighter than air, to diffuse downwards into the roadway, but the ventilation of the mine keeps up a steady flow of fresh air and gradually accumulations of methane are removed (Fig. 31).

This, however, is a very slow process and removal of accumulations of the gas is made by direct ventilation, i.e. by directing the ventilating current into the gas. Brattice cloth (Fig. 32) is placed in the lower portion of the roadway and the ventilating current is confined to the upper space.

Carbon dioxide, which is a constituent of blackdamp, collects near the ground of the workings and it has to be removed for safety purposes. The process of diffusion causes the heavy carbon dioxide molecules to rise into the ventilating air current

and the accumulations of carbon dioxide are gradually removed (Fig. 33).

Again this is a very slow process and for rapid removal of

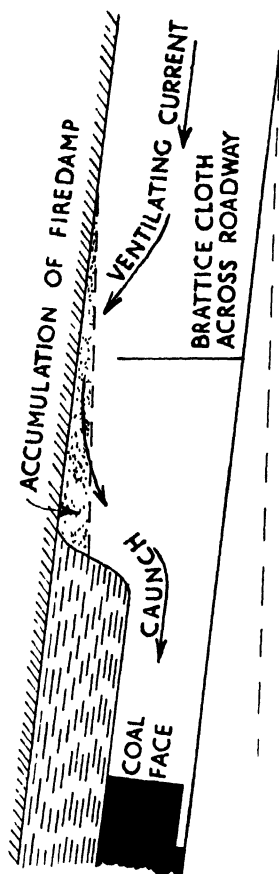


FIG. 32

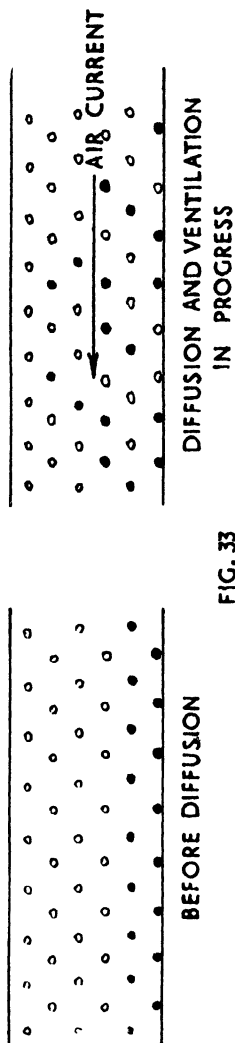


FIG. 33

blackdamp the ventilating current is directed into the gas by means of brattice cloth.

Colliery officials are required to ensure that the ventilation

of the mine is such that the statutory limits in relation to safety in mines are not exceeded. When the general body of the air in a working place contains $1\frac{1}{4}$ per cent. of methane all electricity is cut off from cables and electrical appliances. If the general body of the air contains $2\frac{1}{2}$ per cent. of methane all men are withdrawn. In the case of carbon dioxide the statutory limit is $1\frac{1}{4}$ per cent.

EXERCISES

1. Give definitions of (a) Boyle's Law, (b) Graham's Law. Explain fully how each has an application in the ventilation of mines.

(Min. Sc.; U.L.C.I.)

2. Describe two experiments to illustrate the diffusion of gases. Explain why diffusion takes place. Why is the diffusion of gases of special interest to the miner?

Describe, with sketches, two experiments to show that gases mix by diffusion.

(Min. Sc., U.L.C.I.)

3. Describe an experiment which shows that firedamp diffuses at a greater rate than air. Give an example of the diffusion of gases, taken from the ventilation of the workings of a mine. (Min. Sc ; U.E.I.)

4. State Graham's Law of Diffusion. Describe an experiment which shows that different gases diffuse at different rates. Explain how the diffusion of gases affects the composition of mine air.

(Min. Sc.; U.L.C.I.)

CHAPTER V

MECHANICS

FORCE

It is common knowledge that a body at rest remains at rest unless acted upon by a force such as a pull or a push of sufficient magnitude. Also in the case of a body moving with a constant speed in a straight line, a force has to be applied to increase or decrease the speed. Again a force must be applied to change the direction of motion of a body even though the speed of the body may be unchanged.

Representation of a Force

If a string AB is fastened to a hook in the wall and pulled in the direction AB (Fig. 34a) with a force equal to 10 lb. wt., the force on the hook can be represented by a straight line CD, 5 in. long (scale 1 in. = 2 lb. wt.), where CD is parallel to AB. The arrow shows that the force is a pull which acts in the direction C to D. If a rod EF is hinged to the wall at a point E (Fig. 34b) and a push of 10 lb. wt. is applied along FE, this force can be represented by a straight line GH, 5 in. long (scale 1 in. = 2 lb. wt.) where GH is parallel to FE.

It will be noticed that either a pull along EF or a push along FE can be applied in the rod EF (Fig. 34b), whereas in the case of the string AB (Fig. 34a) only a pull can be applied in the direction AB.

Thus a force can be represented by a straight line (a) in magnitude by the length of the line drawn to scale, (b) in direction by the direction of the line and (c) in sense by an arrow.

Resultant of Two Forces, acting at a Point in the same Straight Line

If the string (Fig. 34a) is pulled by two persons, one with a force of 10 lb. wt. and the other with a force of 15 lb. wt., the combined effect of these two forces is a force of 25 lb. wt. Again, in the case of a cage ascending a shaft, if the upward pull in the winding rope is 2,000 lb. wt. and the weight of the cage, contents, etc., acting vertically downwards, is 1,900 lb. wt., then the combined effect of the two forces is an upward

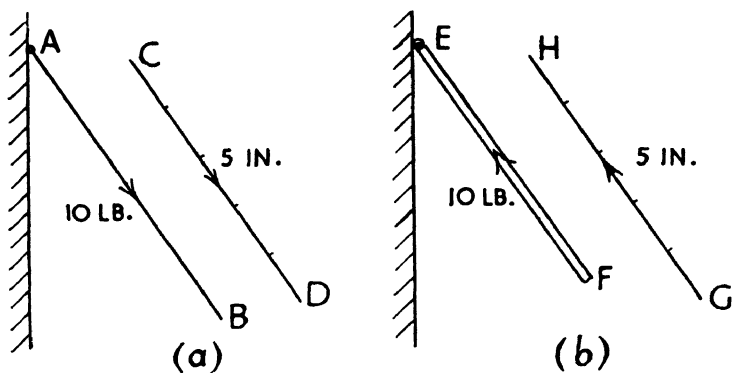


FIG. 34

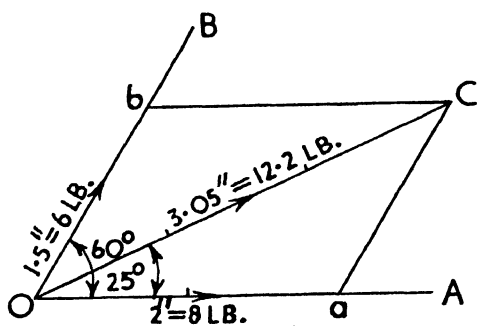


FIG. 35

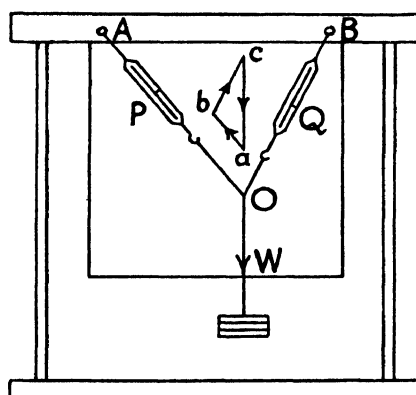


FIG. 36

force of 100 lb. wt. which produces the upward motion of the cage. The combined effect of the two forces in each of the above cases, is known as the resultant. Thus the resultant of two forces, acting at a point, in the same straight line and in the same direction, is the sum of the two forces. The resultant of two forces, acting at a point, in the same straight line and in opposite directions, is the difference of the two separate forces and the point of application moves in the direction of the larger force.

When two forces, acting at a point, are inclined at an angle to each other, the resultant can be determined by the following law.

PARALLELOGRAM OF FORCES

If two forces, acting at a point, are represented in magnitude and direction by the adjacent sides of a parallelogram, the resultant of these two forces can be represented in magnitude and direction by the diagonal of the parallelogram passing through this point.

Example. Two forces, one of 8 lb. wt. and the other of 6 lb. wt., act at a point and make an angle of 60° with each other. Find the magnitude of the resultant force and the angle which the resultant makes with the larger force.

Suppose O (Fig. 35) represents the point of application of the forces. Let the force of 8 lb. wt. act along OA and the force of 6 lb. wt., along OB, the angle BOA being 60° .

If the scale, 1 in. = 4 lb. wt., is chosen and Oa and Ob are marked off to equal 2 in. and 1.5 in. respectively, when the parallelogram OaCb is completed, the diagonal OC is found to be 3.05 in. long.

Hence the resultant = 3.05×4 lb. wt.

$$= 12.2 \text{ lb. wt.}$$

Also $\angle COa = 25^\circ$.

TRIANGLE OF FORCES

Fig. 36 shows two spring balances P and Q, attached to the pegs A and B, which are fixed to a stand. The hooks of the balances are connected by a suitable length of string and another piece of string which supports a known weight W is connected to the point O. The system is now balanced with the point O at rest or in equilibrium. A drawing-board to which a sheet of paper is attached is supported just behind the strings. If a point *a* is marked on the paper and the lines *ab* and *bc* are drawn parallel to OA and OB respectively, to represent the forces in the spring balances P and Q to scale, when the points *c* and *a* are joined, the line *ca* is vertical and parallel to the string supporting the weight W.

If the string supporting W is moved into another position, similar results are obtained. A table of results is shown below (scale 1 in. = 1 lb.).

P (lb.)	Q (lb.)	W (lb.)	ab (in.)	bc (in.)	ca (in.)
3.5	2.5	4	3.5	2.5	3.9
3.0	3.1	4	3.0	3.1	4.1
2.9	2.6	4	2.9	2.6	4.0

In each of the above cases the forces P and Q are represented in magnitude and direction by the straight lines ab and bc and in each case the remaining side ca represents the remaining force W in magnitude and direction. We are thus led to the Triangle Law of Forces, which may be stated as follows: *If three forces, acting at a point, are in equilibrium they can be represented in magnitude and direction by the sides of a closed triangle, taken in order.*

Let the forces P , Q and R , acting at O , be in equilibrium (Fig. 37). If the sides ab , bc and ca of the triangle abc are parallel to the directions of the forces P , Q and R respectively and the side ab represents the force P in magnitude, then the remaining sides bc and ca represent the forces Q and R respectively in magnitude. Thus we see that if the magnitude of one force and the directions of the three forces are known, then the magnitudes of the two remaining forces can be calculated.

Equilibrium and Equilibrant

If only the forces P and Q act on a particle at O (Fig. 37) the particle will move along the direction of the resultant. If, however, a force R is applied so as to keep the particle at rest or in equilibrium, this force R is the equilibrant of the two forces P and Q . Similarly the force Q is the equilibrant of the forces P and R and the force P is the equilibrant of the forces R and Q .

Example. A string AC supports a load of 50 lb. wt. Another string is attached to a point B of the first string and is pulled in a horizontal direction BD , so that AB makes an angle of 30° with the vertical (Fig. 38). Determine the forces in BA and BD .

If we draw PQ vertical and equal to 5 in. (scale 1 in. = 10 lb. wt.) and we also draw QR and PR parallel to BD and AB respectively, then $QR = 2.8$ in. and $RP = 5.7$ in.

Hence the force in $BD = 2.8 \times 10$ lb. wt.
 $= 28$ lb. wt.

and the force in $BA = 5.7 \times 10$ lb. wt.
 $= 57$ lb. wt.

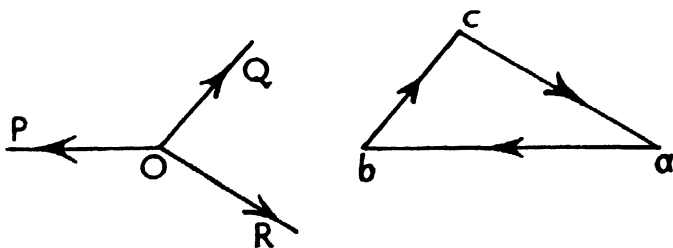


FIG. 37

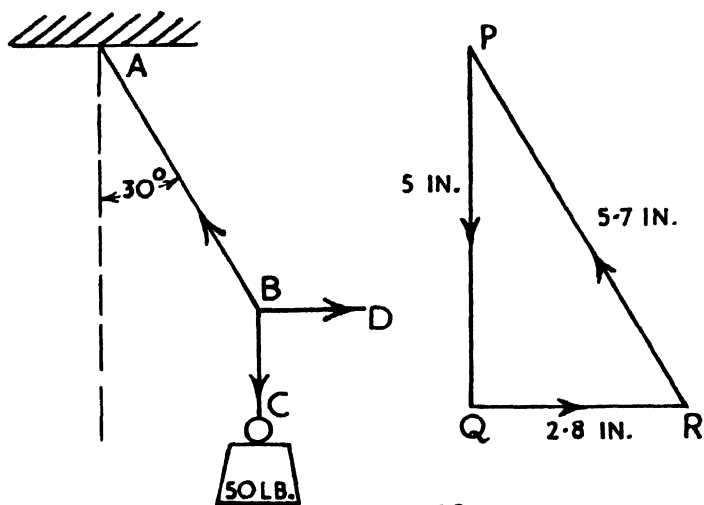


FIG. 38

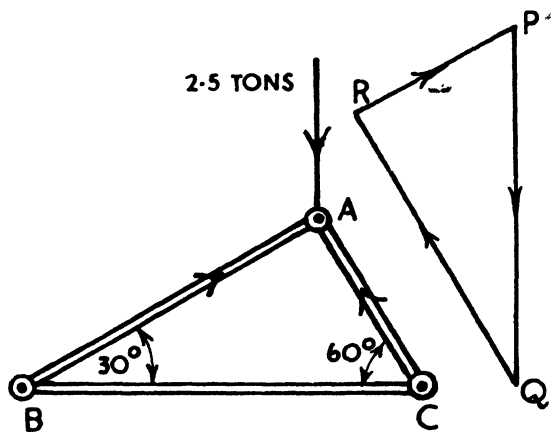


FIG. 39

Example. The framework ABC (Fig. 39) forms part of the structure of a colliery winding head gear. A vertical load of 2.5 tons acts on the point A. Find the forces in the members BA and CA.

If we draw PQ vertical 5 in. long (scale 1 in. = $\frac{1}{2}$ ton) and QR and PR parallel to CA and AB respectively, then QR = 4.3 in.

Hence the force in CA, acting from C to A,

$$= 4.3 \times 0.5 \text{ tons}$$

$$= 2.15 \text{ tons.}$$

Also

$$RP = 2.5 \text{ in.}$$

Hence the force in BA, acting from B to A

$$= 2.5 \times 0.5 \text{ tons}$$

$$= 1.25 \text{ ton.}$$

MOMENTS

Consider a spanner AB (Fig. 40a). If a force of 10 lb. wt is applied at A at right angles to its length and at 6 in. from the centre C of the nut, the turning effect is greater than if the 10 lb. wt. were applied at A₁, where A₁C is 4 in. Again, if a force of 20 lb. wt. be applied at A at right angles to its length, the turning effect is greater than when a force of 10 lb. wt. is applied. This turning effect, or moment as we shall term it, depends on (a) the force applied along AF and on (b) the distance of the force from the point about which the turning is taking place.

The moment of a force about a point is sometimes called the torque and is defined as the product of the force and the perpendicular distance of the force from the point. Thus we have:

$$\text{Moment or Torque} = \text{Force} \times \text{Perpendicular Distance}$$

When a force of 10 lb. wt. is applied along AF, the moment is 10 lb. \times 6 in., i.e. 60 lb. in.

It is important to remember that in calculating moments, it is the perpendicular distance which is taken. This is illustrated by the following example. In Fig. 40b AB represents the connecting-rod of an engine and OA the crank. If F is the force along the connecting rod, the turning moment on the flywheel is given by $F \times OC$, where OC is the perpendicular distance between the crankshaft and the connecting-rod.

Clockwise and Counter-clockwise Moments

Suppose the point about which moments are taken is the centre O of the face of a clock. Then the moment of the force F about the point O is a clockwise moment, since the turning is in the same direction as the motion of the hands of a clock (Fig. 41a). If the turning is counter-clockwise, the moment of

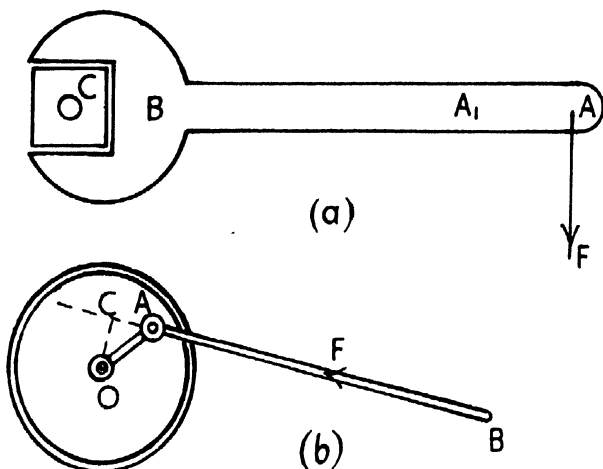


FIG. 40

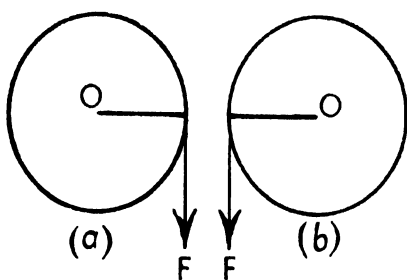


FIG. 41

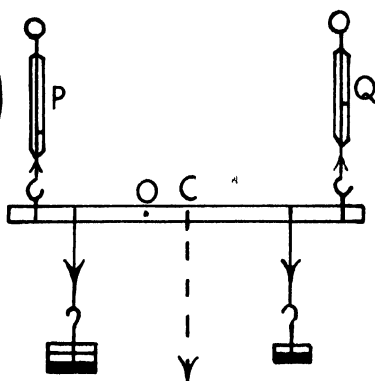


FIG. 42

the force F about the point O is called a counter-clockwise moment (Fig. 41b).

Fig. 42 shows two spring balances P and Q which support a uniform rod in a horizontal position, the supporting strings being vertical. The rod is in equilibrium under the action of two

upward forces whose values are indicated on the spring balances and three downward forces. (N.B. Since the rod can be balanced at its centre C, the weight of the rod may be considered to act vertically downwards through this point.) If a point O is chosen on the rod and the distance of each force from this point is measured, the moment of each force about O may be calculated and the sum of the clockwise moments may be compared with the sum of the counter-clockwise moments. If the weights are moved into new positions or a different point O is chosen, a set of results as shown in the following table can be obtained.

Sum of Clockwise Moments (lb. in.)	Sum of Counter-clockwise Moments (lb. in.)
$(4.5 \times 5) + (0.5 \times 2) + (5 \times 8)$ $= 63.5$	$(4 \times 2.1) + (4 \times 13.5)$ $= 62.4$
$(4.5 \times 7.5) + (5 \times 5.5)$ $= 61.3$	$(4 \times 4.6) + (0.5 \times 0.5) + (4 \times 10.8)$ $= 61.9$

PRINCIPLE OF MOMENTS

The results in the previous table verify the Principle of Moments which states that *if a number of forces, acting in the same plane, keep a body in equilibrium, the sum of the clockwise moments about any point in the plane is equal to the sum of the counter-clockwise moments about the same point.*

Upward and Downward Forces

With the apparatus shown in Fig. 42 the sum of the upward forces (i.e. the sum of the readings given by the balances) may be compared with the sum of the downward forces (i.e. the sum of the two hanging weights and the weight of the rod). When the weights are moved into different positions and the observations are repeated, a table of results similar to the following may be obtained.

Sum of Upward Forces (lb. wt.)	Sum of Downward Forces (lb. wt.)
$6.25 + 5.25 = 11.5$	$4 + 7 + 0.5 = 11.5$
$4.2 + 7.3 = 11.5$	$4 + 7 + 0.5 = 11.5$

These results show that *if a bar is at rest under a system of vertical forces, the sum of the upward forces is equal to the sum of the downward forces.*

Example. A uniform beam AB, 20 feet long and weighing 100 lb., rests horizontally on two supports, one at the end A and the other at the end B. Vertical loads of 120 lb. and 180 lb. are applied at distances of 8 ft. and 12 ft. respectively from the end A. Find the upward forces at the supports (Fig. 43).

Let X = upward force at A.

and Y = upward force at B.

Taking moments about A, we have:

Sum of clockwise moments = Sum of counter-clockwise moments.

$$120 \times 8 \text{ lb. ft.} + 100 \times 10 \text{ lb. ft.} + 180 \times 12 \text{ lb. ft.} = 20Y \text{ lb. ft.}$$

[N.B. A uniform rod can be balanced at its centre. Hence the weight of the rod may be considered to act vertically downwards through its centre.]

$$\therefore 960 + 1,000 + 2,160 = 20Y.$$

$$\therefore Y = 206 \text{ lb.}$$

$$\text{But } X + Y = 120 + 100 + 180.$$

$$\therefore X + 206 = 120 + 100 + 180.$$

$$\therefore X = 400 - 206.$$

$$= 194 \text{ lb.}$$

LEVERS

A lever is a rigid bar which is capable of turning about a pivot or a fulcrum. By means of a lever a load may be raised or a resistance overcome by applying an effort at a more convenient point. In Fig. 44 several types of lever are shown. In each case, taking moments about the fulcrum F, we have:

$$Pa = Wb,$$

where

W = the resistance or load

and

P = the effort.

The Bent Lever

In some cases the lines of action of the resistance and the effort are inclined at an angle to each other. The lever used in this case is shown in Fig. 45, where W is the resistance acting at right angles to OB and P is the effort, applied at right angles to OA . Taking moments about the fulcrum O , we have:

$$P \cdot OA = W \cdot OB.$$

Example. In the lever shown in Fig. 45, the lengths of the arms OA and OB are 10 in. and 6 in. respectively. What effort applied at A, at right angles to the arm OA , is required to overcome a resistance of 1,000 lb. applied at B, at right angles to OB ?

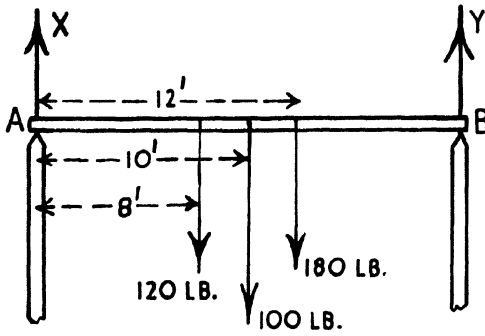


FIG. 43

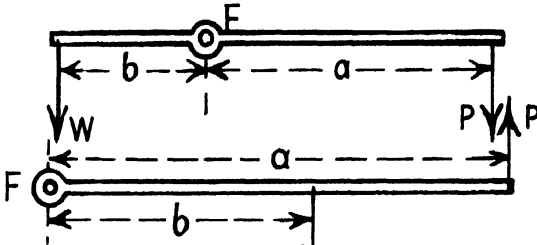


FIG. 44

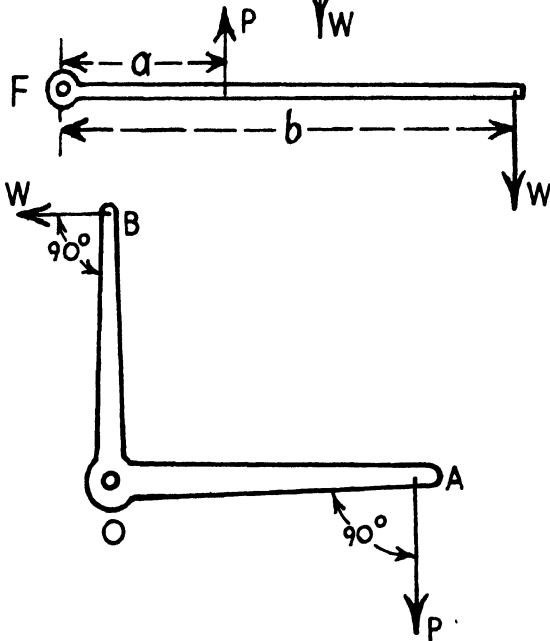


FIG. 45

Let P = the effort.

Taking moments about O , we have:

$$P \times 10 \text{ (lb. in.)} = 1,000 \times 6 \text{ (lb. in.)}$$

$$\therefore P = \frac{1,000 \times 6}{10} \\ = 600 \text{ lb.}$$

PRACTICAL APPLICATIONS

Fig. 46 shows a crowbar AB which is used for raising an edge of a large boulder from the ground. The fulcrum F is a small piece of stone. The force exerted by the boulder on the end B represents the load W while the effort P is applied at the end A .

Fig. 47 shows a lever safety valve, used with a steam-engine boiler. The valve V , attached to the point A , is held down by the load W which is placed at B . The force exerted by the steam may be considered to be the effort P which is required to raise the load W and since F is the fulcrum we have:

$$Pa = Wb.$$

Fig. 48 shows a portion of the lever system used for applying the brake to a haulage wheel or winding engine drum. The lever A which carries the brake-shoe B is pivoted at C . A horizontal rod D is pinned at one end to the upper end of the lever A , and at the other end to the toggle E , which is pivoted at the upper end of the lever F . The brake-shoe G is fixed to this lever. A horizontal effort P is applied along the rods D and H from left to right and the brake-shoes B and G are pressed tightly against the rim of the wheel. Considering the lever A , the force W exerted by the rim of the wheel on the brake-shoe B corresponds to the load and we have:

$$Pa = Wb.$$

The frictional resistance (see p. 55) between the wheel and the brake-shoes brings the wheel to rest.

COUPLES

Suppose a force P acts at each end of a lever AB , pivoted at its centre O , the forces being at right angles to the lever (Fig. 49a). When each force produces a moment of the same sense about O , the sum of the moments

$$= P \cdot AO + P \cdot BO \\ = P \cdot AB.$$

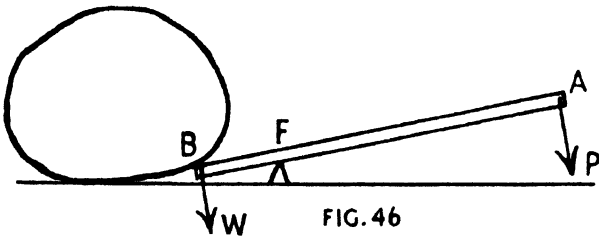


FIG. 46

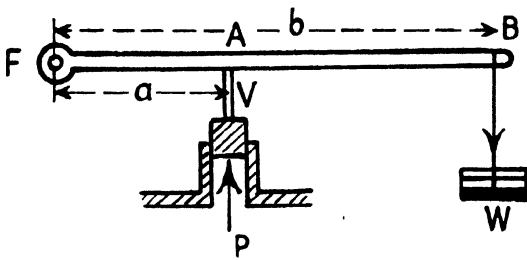


FIG. 47

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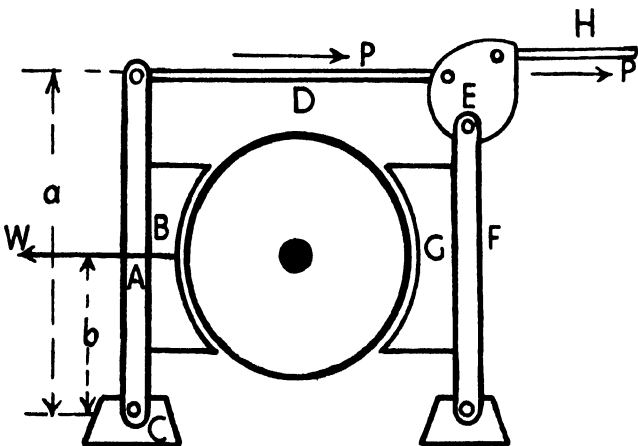


FIG. 48

The two forces in the above case constitute a couple and the moment of the couple = one force \times perpendicular distance between the forces.

Example. A force of 10 lb. wt. is applied tangentially at each end of a diameter of a circular tap of a compressed-air receiver (Fig. 49b). If the diameter of the tap is 2.5 in., find the moment of the couple applied to the tap.

$$\text{Radius of tap} = \frac{2.5}{2} \text{ in.}$$

$$\begin{aligned} \text{Moment of couple} &= 10 \text{ lb.} \times 1.25 \text{ in.} + 10 \text{ lb.} \times 1.25 \text{ in.} \\ &= 12.5 \text{ lb. in.} + 12.5 \text{ lb. in.} \\ &= 25 \text{ lb. in.} \end{aligned}$$

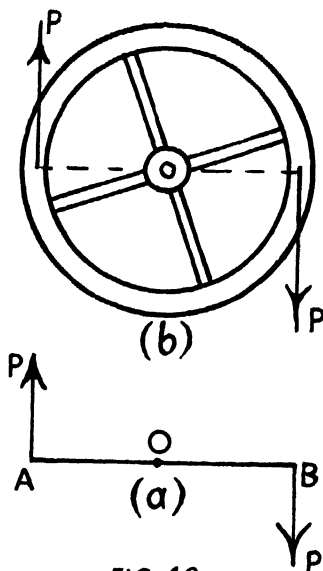


FIG. 49

FRICTION

If a block of wood rests on a table, a horizontal force must be applied to the block in order to move it along the table. Although the surfaces in contact may appear to be smooth, when examined by a microscope they are found to possess irregularities or prominences. When the surfaces are in contact, these prominences interlock and a horizontal force must be applied to the block to cause the prominences of its surface to ride over or wear away those of the other surface. If the surfaces are pressed together, this horizontal force must be increased.

The resistance to be overcome in order for one surface to slide over the other surface is known as the frictional force.

Fig. 50 shows a block of wood resting on a horizontal surface. If a horizontal force P is applied to the block, not sufficient to move it, a frictional force F which is equal to the force P acts between the block and the surface in the opposite direction. If the force P is gradually increased, the frictional force F also increases, still remaining equal to the force P , until the block just begins to move. The value of the frictional force in this case is known as the limiting frictional force.

The Relation between the Frictional Force and the Load

Fig 51a shows the board AB on a table with a wooden slider S resting on the board. One end of a piece of string is attached to a hook in the slider and, after passing over the pulley P , the string supports a slotted weight holder. If a 1 lb. weight is placed on the slider and weights (tenths and hundredths of a lb.) are added to the string until the slider just begins to move, the force required to just overcome the frictional force F may be determined. In the same way when loads of 2 lb., 3 lb., etc., are placed on the slider, the force required to just overcome the frictional force may again be determined. A set of results is shown below:

Weight of slider = 0.2 lb.

Load (W) lb.	Fractional Force (F) lb.	$\frac{F}{W}$
1.2	0.25	0.21
2.2	0.45	0.20
3.2	0.66	0.21
4.2	0.81	0.19
5.2	1.04	0.20

From the graph (Fig. 51b) and also from the last column of the table, it will be seen that

$\frac{F}{W}$ is approximately constant.

This constant is known as the coefficient of friction and is generally denoted by the symbol μ where

$$\mu = \frac{F}{W}$$

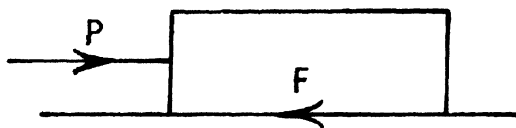


FIG. 50

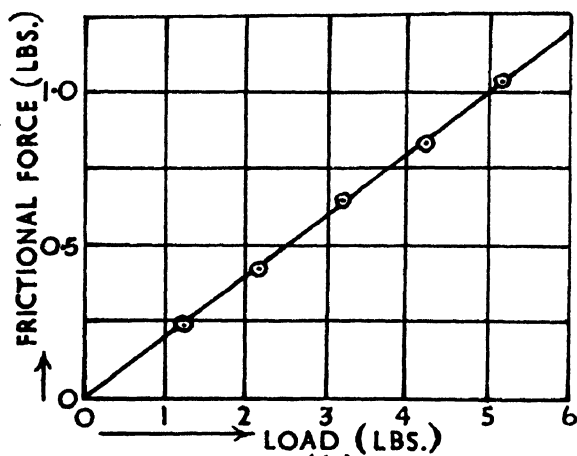
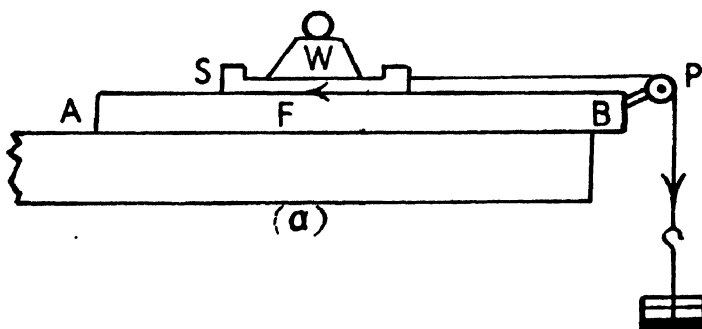


FIG. 51

i.e. Coefficient of Friction (μ) = $\frac{\text{Frictional Force (F)}}{\text{Load (W)}}$

This result is really a special case of the more general result:

$$\mu = \frac{F}{R},$$

where R is the perpendicular force between the two surfaces (Fig. 52).

Example. A brake is applied to the rim of an endless rope haulage surge wheel and the perpendicular force between the brake block and the wheel is 150 lb. wt. If the coefficient of friction between the block and the rim is 0.35, find the frictional force tending to stop the wheel.

From $\mu = \frac{F}{R}$ we have:

$$R = 150 \text{ lb. wt. and } \mu = 0.35.$$

$$\text{Hence } 0.35 = \frac{F}{150}$$

$$\therefore F = 150 \times 0.35 \text{ lb.} \\ = 52.5 \text{ lb.}$$

WORK

Work is done when the point of application of a force moves. When a body of mass one pound is raised through a vertical distance of one foot, a force of 1 lb. wt. acts vertically upwards against the weight of the body and its point of application moves through a vertical distance of 1 ft. In this case the work done is the foot-pound (ft.-lb.). Thus we may define the unit of work in the English system as the work done by a force of 1 lb. wt. in moving its point of application through a distance of 1 ft. in the direction of the force.

Suppose a force of F lb. wt. moves its point of application through a distance of d feet.

Then work done by a force of 1 lb. wt. through 1 ft. = 1 ft.-lb.

\therefore work done by a force of F lb. wt. through 1 ft. = F ft.-lb.

\therefore work done by a force of F lb. wt. through d feet = Fd ft.-lb.

Denoting the work done by W , we have:

$$W = F \times d.$$

Example. Find the work done in raising a load of 25 lb. wt. through a vertical distance of 11.5 ft.

$$\text{Work done} = 25 \text{ lb.} \times 11.5 \text{ ft.} \\ = 287.5 \text{ ft.-lb.}$$

Example. A cage weighs 2,000 lb. and the winding rope weighs $1\frac{1}{2}$ lb. per foot. Find the work done in raising the cage from the bottom of a shaft 500 ft. deep to the surface.

$$\begin{aligned}\text{Work done in raising cage} &= 2,000 \text{ lb.} \times 500 \text{ ft.} \\ &= 1,000,000 \text{ ft.-lb.}\end{aligned}$$

$$\begin{aligned}\text{Work done in raising winding rope} &= \text{Weight} \times \text{average distance raised}\end{aligned}$$

$$= 500 \times 1\frac{1}{2} \text{ lb.} \times \frac{500}{2} \text{ ft.}$$

$$= 187,500 \text{ ft.-lb.}$$

$$\begin{aligned}\text{Total work done} &= 1,000,000 \text{ ft.-lb.} + 187,500 \text{ ft.-lb.} \\ &= 1,187,500 \text{ ft.-lb.}\end{aligned}$$

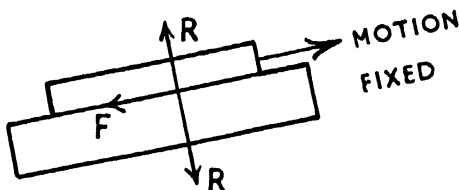


FIG. 52

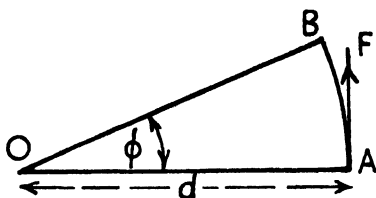


FIG. 53

Work done by a Torque

Suppose O represents the centre of a nut which is being turned by a spanner (Fig. 53). If a force F be applied at the end A of the spanner and the spanner is turned from the position OA to the position OB, then the work done by the force F

$$= F \times \text{arc AB,}$$

assuming that the force always acts at right angles to the spanner.

$$\begin{aligned}\therefore \text{Work done} &= F \times \frac{\text{Arc AB}}{\text{OA}} \times \text{OA} \\ &= Fd \times \text{angle BOA expressed in radians} \\ &= \text{Torque} \times \text{angle of twist in radians}\end{aligned}$$

i.e. $W = T\phi$,

where T is the torque, ϕ the angle of twist and W the work done.

Example. A mean force of 50 lb. wt. is applied at the end of a spanner which is turning a screw. The distance between the force and the centre of the nut is 1.5 ft. Find the work done in turning the spanner through 30° .

$$\begin{aligned}\text{Torque} = T &= 50 \times 1.5 \text{ lb. ft.} \\ &= 75 \text{ lb. ft.}\end{aligned}$$

$$\begin{aligned}\text{Angle of twist in radians } \phi &= \frac{30}{360} \times 2\pi \\ &= \frac{\pi}{6} \\ &= 0.524 \text{ radians.}\end{aligned}$$

$$\begin{aligned}\therefore \text{Work done} = W &= T\phi \\ &= 75 \times 0.524 \text{ ft.-lb.} \\ &= 39.3 \text{ ft.-lb.}\end{aligned}$$

POWER

Power is the rate of doing work. If 20 ft.-lb. of work are performed in two seconds, the power or rate of working is 10 ft.-lb. per second.

Horse Power

The unit of power is the Horse Power which is equal to a rate of working of 33,000 ft.-lb. per minute or 550 ft.-lb. per second.

Example. A pump raises 1,000 gallons of water from a sump through a vertical distance of 20 ft. in 25 minutes. At what horse power does the pump work? (1 gallon of water weighs 10 lb.)

$$\text{Weight of water raised} = 1,000 \times 10 \text{ lb.}$$

$$\text{Work done in 25 minutes} = 1,000 \times 10 \times 20 \text{ ft.-lb.}$$

$$\begin{aligned}\therefore \text{Work done per second} &= \frac{1,000 \times 10 \times 20}{25 \times 60} \text{ ft.-lb.} \\ &= 133.3 \text{ ft.-lb.}\end{aligned}$$

$$\begin{aligned}\therefore \text{Horse Power} &= \frac{133.3}{550} \\ &= 0.24.\end{aligned}$$

EXERCISES

1. Explain what is meant by the term "friction." A haulage engine draws a load of 25 tons along a level road. Find the pull needed if the friction is 0.05 of the load. (Min. Sc.; U.L.C.I.)

2. Define force, work, and power. State the units in which each is measured. The pull in a haulage rope is 10 cwt. and the rope speed is 6 m.p.h. Calculate the H.P. transmitted through the rope.

(Min. Sc.; U.L.C.I.)

3. A uniform bar AB is 10 ft. long and weighs 120 lb. It carries a load of 330 lb. at a point 8 ft. from A. The bar is hinged at A, and a rope inclined at 45° to AB is attached to B and keeps the bar horizontal. What is the pull in the rope?

(Min. Sc.; U.L.C.I.)

4. What is the moment of a force?

Describe two methods of using a crowbar to overturn a heavy stone.

(Min. Sc.; U.L.C.I.)

5. Explain (a) the effects of a force on any body; (b) how a force may be measured; (c) how a force may be represented.

A load of 200 lb. is supported by ropes from two points x and y 10 ft. apart on a horizontal girder. The load hangs 8 ft. vertically below a point on the girder 3 ft. along xy . Determine the pull in each rope.

(Min. Sc.; U.L.C.I.)

6. The lever safety valve on a boiler is $2\frac{1}{4}$ in. in diameter and weighs 4 lb. It is attached to the lever at a point 3 in. from the fulcrum. The lever is 33 in. long, weighs 9 lb. and its centre of gravity is at a distance of 12 in. from the fulcrum. What weight must be suspended at the end of the lever if the valve is to open when the steam pressure is 150 lb. per sq. in.?

(Min. Sc.; U.L.C.I.)

7. How much work is done in punching a hole through a wrought-iron plate 1 in. thick if the mean force on the punch is 80 tons?

(Min. Sc.; U.L.C.I.)

CHAPTER VI

THERMOMETRY AND EXPANSION

EXPANSION

All substances, with one or two exceptions, whether solid, liquid or gas, expand when heated and contract when cooled. This expansion and contraction is illustrated by the following experiments.

In Fig. 54a AB represents an iron rod and CD an iron frame. Each is mounted on a wooden handle. The rod exactly fits into the frame and the end of the rod fits into the circular hole E. When the rod is heated, however, it no longer fits into the frame and the end of the rod can no longer be inserted in the hole E. The rod has expanded lengthways and also sideways. But when the rod cools to air temperature, it will again fit the frame.

To show the expansion of a liquid, the apparatus shown in Fig. 54b is used. A flask is provided with a tight-fitting rubber stopper through which a glass tube passes. The flask and a portion of the tube contain coloured water. When the flask is placed in a water bath which is heated by a bunsen burner, the liquid falls from A to B and then finally rises to C. During the initial heating the inside of the flask expands more than the liquid, causing the liquid level to fall from A to B. But finally the liquid expands more than the vessel and this is shown by the rise of the liquid from B to C.

To show the expansion of a gas (e.g. air) we use the apparatus shown in Fig. 54c. If the stopper and glass tube fit airtight and the hands are placed over the flask, bubbles of air appear in the water. This shows that the air has expanded due to the heat from the hands. When the flask cools the water rises in the tube, showing that the air contracts when cooled.

HEAT AND TEMPERATURE

Just as water flows from a high level to a low level, so heat flows from a point of high temperature to a point of low temperature. Thus temperature is analogous to water level and flow of heat corresponds to flow of water. Heat is therefore a quantity which can be measured in heat units, while temperature is the degree of heat of a body.

THE THERMOMETER

The thermometer is an instrument for measuring temperature. It consists of a graduated tube of narrow bore, with a bulb at one end, the other end being closed. Mercury is contained in the bulb and when the temperature increases the mercury expands and rises up the tube (Fig. 55).

The Fixed Points of a Thermometer

Before a scale can be engraved on the stem of an ungraduated thermometer the fixed points must be marked. These fixed points are (a) the Freezing Point of pure water and (b) the Boiling Point of pure water under normal atmospheric pressure, viz. 76 cm. of mercury.

To mark the freezing point the bulb is allowed to remain in a mixture of ice and water (free from impurities) and the stem is marked opposite the mercury level (Fig. 56a). To mark the boiling point, the bulb is placed in the steam from boiling water in a hypsometer (Fig. 56b) and the stem is again marked opposite the mercury level.

Scales of Temperature

The freezing point is marked 0° Centigrade (0° C.) or 32° Fahrenheit (32° F.) and the boiling point is marked 100° Centigrade (100° C.) or 212° Fahrenheit (212° F.).

Fig. 57 shows two identical thermometers, except one is marked on the Centigrade scale and the other on the Fahrenheit scale.

If F is the Fahrenheit reading corresponding to the Centigrade reading C, we have:

$$\frac{XB}{AB} = \frac{YD}{ED}$$

$$\text{i.e.} \quad \frac{C-0}{100-0} = \frac{F-32}{212-32}$$

$$\text{or} \quad \frac{C}{100} = \frac{F-32}{180}$$

Example. Convert 20° C. into the Fahrenheit scale.

In the formula $\frac{C}{100} = \frac{F-32}{180}$, substitute $C=20$.

$$\text{Hence} \quad \frac{F-32}{180} = \frac{20}{100}$$

$$\therefore \quad F = \frac{180}{100} \times 20 + 32$$

$$= 68^{\circ} \text{ F.}$$

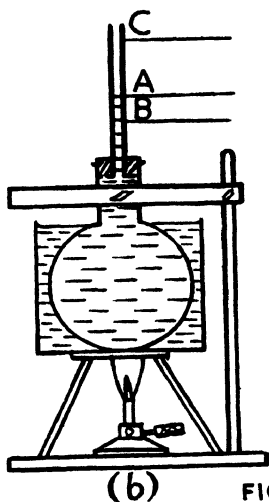
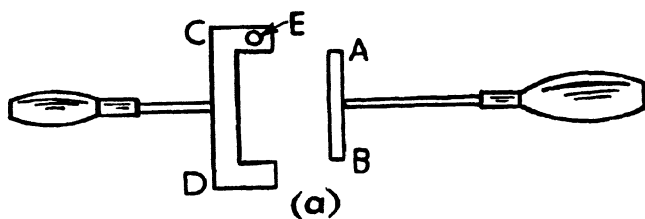


FIG. 54

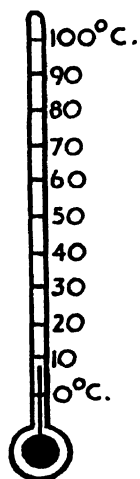
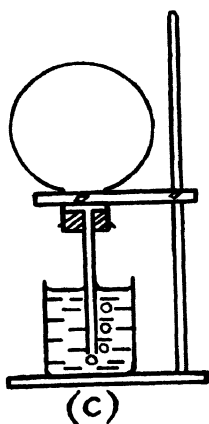


FIG. 55

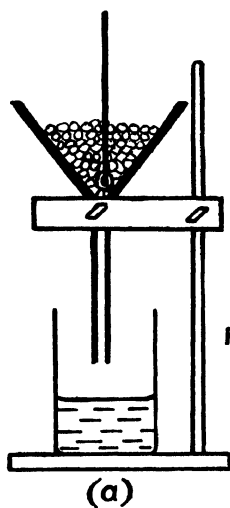
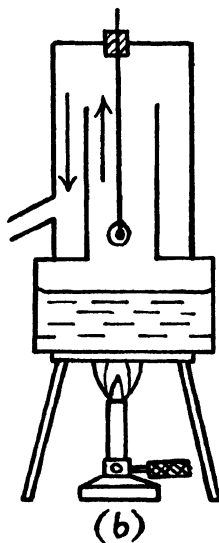


FIG. 56



Example. Convert 20° F. into the Centigrade scale.

In the above formula substitute $F=20$.

$$\text{Hence} \quad \frac{20-32}{180} = \frac{C}{100}$$

$$\therefore \quad C = \frac{100}{180} (20 - 32) \\ = -6.67^{\circ} \text{ C.}$$

EXPANSION OF SOLIDS

It is a common statement that one solid expands more than another. What is implied is that a rod of one material expands more than a rod of another material of the same length and for the same temperature increase. We are thus led to the idea of *coefficient of linear expansion*, which may be defined as *the increase in length of a solid per unit length per degree rise in temperature*.

Example. An iron rod 100 cm. long is heated from 15° C. to 100° C. Find the increase in length, if the coefficient of linear expansion of iron is 0.000011 per deg. C.

$$\begin{aligned} \text{Increase in temperature} &= (100 - 15)^{\circ} \text{ C} = 85^{\circ} \text{ C.} \\ \text{Expansion of 1 cm. for } 1^{\circ} \text{ C.} &= 0.000011 \text{ cm.} \\ \text{Expansion of 100 cm. for } 1^{\circ} \text{ C.} &= 100 \times 0.000011 \text{ cm.} \\ \text{Expansion of 100 cm. for } 85^{\circ} \text{ C.} &= 100 \times 0.000011 \times 85 \text{ cm.} \\ &= 0.0935 \text{ cm.} \end{aligned}$$

Let L = initial length of a solid,
 t = temperature increase,
 a = coefficient of linear expansion,
 x = the expansion.

Then expansion of 1 unit of length for 1 degree = a ,
 expansion of L units of length for 1 degree = La ,
 and expansion of L units of length for t degrees = Lat ,
 i.e. $x = Lat$.

Also Final length = Initial length + Expansion.

Units

Now 1 cm. of iron expands 0.000011 cm. for 1° C. rise in temperature or:

$$\begin{aligned} \text{Coefficient of linear} &= \frac{0.000011 \text{ cm.}}{\text{expansion of iron } 1 \text{ cm.} \times 1 \text{ deg. C.}} \\ &= \frac{0.000011}{1 \text{ deg. C.}} \\ &= 0.000011 \text{ per deg. C.} \end{aligned}$$

Also 1 ft. of iron expands 0.000011 ft. for 1° C. rise in temperature, or:

$$\begin{aligned}\text{Coefficient of linear expansion} &= \frac{0.000011 \text{ ft.}}{1 \text{ ft.} \times 1 \text{ deg. C.}} \\ &= \frac{0.000011}{1 \text{ deg. C.}} \\ &= 0.000011 \text{ per deg. C.}\end{aligned}$$

From these considerations it can be seen that the value of the coefficient of linear expansion is the same number whatever unit of length is employed.

Now let us consider the Fahrenheit scale of temperature. We already know that one Fahrenheit degree is equal to $\frac{5}{9}$ of a Centigrade degree.

Thus 1 ft. of iron for 1° C. rise expands 0.000011 ft.

∴ 1 ft. of iron for 1° F. rise expands $\frac{5}{9} \times 0.000011$ ft.
i.e. 0.0000061 ft.

Hence the value of the coefficient expressed in the Fahrenheit scale is 0.0000061 per deg. F. The value of the coefficient is therefore dependent on the scale of temperature used.

Example. A line of cast-iron pipes is 150 feet long at 20° C. How much does the pipe-line expand when steam at 100° C. is passed through it? Coefficient of linear expansion of cast iron = 0.000012 per deg. C.

Expansion of 1 ft. for 1° C. rise = 0.000012 ft.

∴ 150 ft. for 1° C. ∴ = 150 × 0.000012 ft.

∴ 150 ft. for 80° C. ∴ = 150 × 0.000012 × 80 ft.

= 0.144 ft.

= 1.73 in.

Example. The measured length between two points by means of a surveyor's chain at 60° F. is 120.55 yd. Find the true length if the chain is correct at 32° F. Coefficient of linear expansion of steel = 0.0000067 per deg. F. (see p. 68).

Expansion of chain = Length × Coefft. of linear expansion × Temperature change.

= 120.55 × 0.0000067 × 28 yd.

= 0.02 yd.

True length = 120.55 yd. + 0.02 yd.

= 120.57 yd.

Determination of the Coefficient of Linear Expansion of a Metal Tube

The metal tube XY which is provided with an inlet and an outlet for steam is supported vertically in a wooden stand and held in position by means of two brackets A and B (Fig. 58).

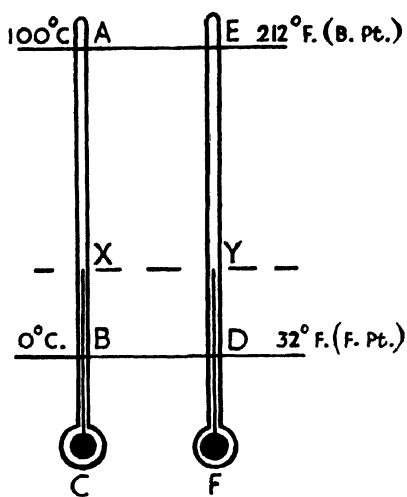


FIG. 57

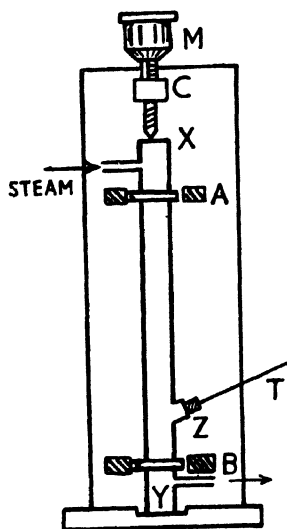


FIG. 58

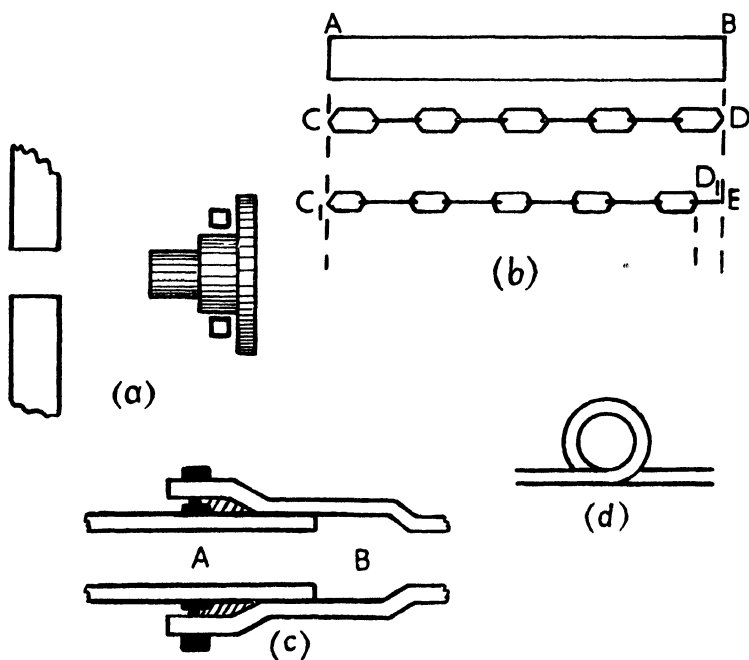


FIG. 59

The lower end of the tube rests on a steel point in a small cavity sunk in the base. A thermometer T fits through a cork which is inserted in a circular aperture Z in the tube. The expansion of the tube is measured by a micrometer screw M, fixed by a bracket C to the wooden stand.

To perform an experiment the length of the tube is first measured and the tube is then placed in its position on the stand. The micrometer screw is adjusted so that its point touches the upper end of the tube. After noting the readings of the micrometer and the thermometer, the screw is raised to allow for the expansion of the tube.

When steam has passed through the tube for about ten minutes, the micrometer screw is again adjusted and its reading is noted along with the reading of the thermometer T. The length of the tube having been measured, the coefficient of linear expansion of the material is calculated in the following manner.

Initial length of tube	=99.5 cm.
Initial micrometer reading	= $3\frac{5.5}{100}$ mm.
Final micrometer reading	= $4\frac{6}{100}$ mm.
Initial temperature	=20° C.
Final temperature	=100° C.
Expansion	= $\frac{9.1}{100}$ mm.
	=0.091 cm.

Hence the coefficient of linear expansion of the material

$$= \frac{0.091 \text{ cm.}}{99.5 \text{ cm.} \times 80 \text{ degrees C.}}$$

$$= 0.00011 \text{ per deg. C.}$$

THE USES OF EXPANSION AND CONTRACTION

In mining engineering, expansion and contraction play a very important part in many constructional processes. In order to fit the crank on a flywheel shaft, the circular hole in the crank is made slightly too small. The crank is heated until it just fits on the shaft and when it cools a tight fit is obtained. This method of fitting is known as a shrink fit.

In some cases expansion fitting is employed. The internal member, e.g. the crankpin (Fig. 59a) is made slightly larger than the circular hole in the crank and the pin is cooled to a low temperature such as the temperature of liquid air (-182°C.). The pin contracts, and when inserted in the hole, it expands and a tight fit is obtained.

Errors due to Expansion in Measuring Instruments

A surveyor's chain consists of links which have a definite length at some specified temperature. When measuring distances with a chain at a temperature higher than this specified temperature, the links have expanded and the measured length is less than the true length.

Suppose AB (Fig. 59b) is the length to be measured and CD the measuring chain. Suppose the length CD of the chain to contract to its length at the specified temperature, i.e. to C_1D_1 . Then the error is the distance D_1E , which is the expansion of the scale.

Allowance for Expansion

In many appliances allowance has to be made for expansion due to increase in temperature. Thus hot-water pipes are fitted with telescopic joints to allow for expansion when hot water passes through them (Fig. 59c). The pipe A expands into the pipe B and buckling is prevented.

In steam pipes used in boilers, loop joints are used to take up the expansion (Fig. 59d).

The above examples are just a few of the practical applications of expansion and contraction of solids. Other examples will no doubt suggest themselves to the student.

EXPANSION OF GASES

We have already seen that change of pressure and change of temperature each produce a change in the volume of a gas. Hence in finding the amount of expansion due to increase in temperature we must eliminate any effect due to change of pressure, by keeping the pressure constant.

We may thus define the *coefficient of expansion of a gas at constant pressure as the increase in volume per unit volume at 0°C. , per degree Centigrade rise in temperature, under the condition of constant pressure.*

This coefficient is $\frac{1}{273}$ per deg. C. We may now enunciate Charles' Law, which states that *a given mass of any gas expands by $\frac{1}{273}$ of its volume at 0°C. for each degree Centigrade rise in temperature, provided the pressure remains constant.*

Suppose V_0 = the volume of a given mass of gas at 0°C.

V_1 = the volume at $t_1^\circ \text{C.}$,

and V_2 = the volume at $t_2^\circ \text{C.}$

Then V_0 c.c. at 0°C. become $V_0 + \frac{V_0}{273}$ c.c. at 1°C. ,

and V_0 c.c. at 0°C. become $V_0 + \frac{V_0 t_1}{273}$ c.c. at $t_1^\circ \text{C.}$,
assuming constant pressure.

$$\text{i.e.} \quad V_1 = V_0 + \frac{V_0 t_1}{273} = V_0 \left(1 + \frac{t_1}{273} \right) \quad \dots \quad (1)$$

$$\text{Similarly} \quad V_2 = V_0 \left(1 + \frac{t_2}{273} \right) \quad \dots \quad (2)$$

Dividing (1) by (2) we have:

$$\frac{V_1}{V_2} = \frac{1 + \frac{t_1}{273}}{1 + \frac{t_2}{273}}$$

$$\text{or} \quad \frac{V_1}{V_2} = \frac{273 + t_1}{273 + t_2} \quad \dots \quad (3)$$

Suppose we choose the temperature -273°C. as the level from which we measure our temperatures. This temperature level, viz. -273°C. , is known as the absolute zero of temperature. Thus we have:

$$\begin{aligned} \text{Absolute Temperature} &= \text{Centigrade Temperature} + 273, \\ \text{or} \quad T_1^\circ \text{ Absolute} &= t_1 + 273. \end{aligned}$$

Writing T_1 for $273 + t_1$ and T_2 for $t_2 + 273$, equation (3) becomes:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\text{i.e.} \quad \frac{V}{T} = \text{a constant.}$$

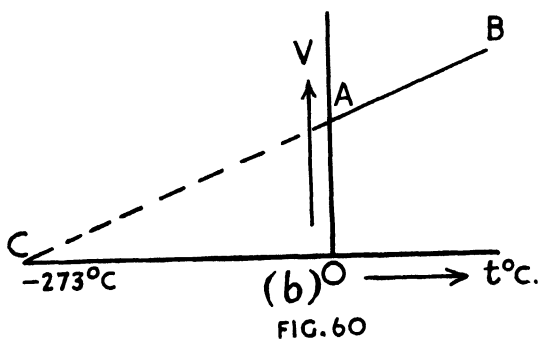
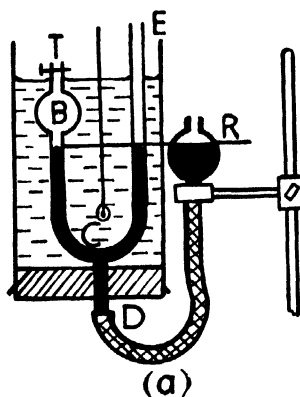
Thus *the volume of a given mass of a gas varies directly as its absolute temperature provided the pressure remains constant.*

Experimental Verification

The above relationship can be verified experimentally by means of the apparatus shown in Fig. 60a. A tube BCE consists of two branches, one leading to the bulb B, fitted with a tap T, and the other open to the atmosphere. A branch tube D passes through a rubber stopper in the base of a large glass vessel and the lower end of the tube D is connected by pressure tubing to a reservoir R. The volume of the bulb is accurately known and the left-hand branch tube leading from it is calibrated in cubic centimetres. Mercury is poured into the tube and the vessel is filled with water.

To perform an experiment the tap T is opened and the

reservoir R is adjusted so that the levels of the mercury columns are just below the bulb. The tap T is then closed, the volume of air in the bulb and tube is read and the temperature is noted. Steam is passed through a delivery tube into the water until the temperature rises about 10°C . The mercury is adjusted to be at the same level in both branches of the tube so as to keep the pressure constant, and the volume of air and the temperature are again noted. This procedure is repeated until a temperature



of 90°C . is reached. The results are tabulated and a graph connecting volume of air and temperature is drawn (Fig. 60b). The graph is the straight line AB and when this line is produced it cuts the axis of temperature at the point C (-273°C).

Thus
$$\frac{V}{273+t} = \text{a constant,}$$

i.e.
$$\frac{\text{Volume}}{\text{Absolute Temperature}} = \text{a constant at constant pressure.}$$

Example. A given quantity of gas occupies a volume of 100 cubic feet at 17° C. The gas is heated at constant pressure to 77° C. Find the volume of the gas at this temperature.

Since the volume is proportional to the absolute temperature, we may write:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2},$$

where V_1 = volume at T_1° Absolute
 and V_2 = volume at T_2° Absolute.
 Substitute $V_1 = 100$ cub. ft.
 $T_1 = 273 + 17^\circ$ Absolute
 $T_2 = 273 + 77^\circ$ Absolute.

$$\therefore \frac{100}{273 + 17} = \frac{V_2}{273 + 77}$$

$$\therefore V_2 = \frac{273 + 77}{273 + 17} \times 100$$

$$= \frac{350}{290} \times 100$$

$$= 120.7 \text{ cub. ft.}$$

Relationship between the Volume, Pressure and Absolute Temperature of a given Mass of a Gas

Let V_1 = the volume of the given mass of gas at T_1° Absolute and pressure P_1

and V_2 = the volume of the given mass of gas at T_2° Absolute and pressure P_2 .

The changes of pressure and temperature both affect the volume.

Let the change of pressure have its full effect at constant temperature.

Then $P_1 V_1 = P_2 v$, where v = some intermediate volume.

Now let the temperature have its full effect at constant pressure.

Then
$$\frac{v}{T_1} = \frac{V_2}{T_2}$$

Eliminating v from the two equations, we have

$$P_1 V_1 = P_2 \cdot \frac{V_2 T_1}{T_2}$$

$$\therefore \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

i.e.
$$\frac{\text{Initial Pressure} \times \text{Initial Volume}}{\text{Initial Absolute Temperature}}$$

$$= \frac{\text{Final Pressure} \times \text{Final Volume}}{\text{Final Absolute Temperature}}$$

Absolute Zero of Temperature on Fahrenheit Scale

$$\begin{aligned}\text{Coefficient of expansion of a gas} &= \frac{1}{273} \text{ per deg. C.} \\ &= \frac{5}{9} \times \frac{1}{273} \text{ per deg. F.} \\ &= \frac{1}{491.4} \text{ per deg. F.}\end{aligned}$$

Hence the absolute zero of temperature is $32^{\circ}\text{ F.} - 491.4^{\circ}\text{ F.}$, i.e. -459.4° F.

Thus Fahrenheit Absolute Temperature
 $= 459.4 + \text{Fahrenheit Temperature.}$

Example. A receiver contains 1,200 cub. ft. of compressed air at a temperature of 85° F. and 75 lb. per sq. in. absolute pressure. What volume would this quantity of air occupy at 60° F. and 15 lb. per sq. in. absolute pressure?

$$\begin{aligned}\text{From} \quad \frac{P_1 V_1}{T_1} &= \frac{P_2 V_2}{T_2}, \\ \text{we have} \quad V_1 &= 1,200 \text{ cub. ft.} \\ P_1 &= 75 \text{ lb. per sq. in.} \\ T_1 &= 459.4 + 85^{\circ} \text{ Absolute} \\ P_2 &= 15 \text{ lb. per sq. in.} \\ T_2 &= 459.4 + 60^{\circ} \text{ Absolute.}\end{aligned}$$

$$\therefore \frac{75 \times 1,200}{459.4 + 85} = \frac{15 V_2}{459.4 + 60}$$

$$\begin{aligned}\therefore V_2 &= 1,200 \times \frac{75}{15} \times \frac{519.4}{544.4} \text{ cub. ft.} \\ &= 5,724 \text{ cub. ft.}\end{aligned}$$

CHANGE OF DENSITY OF A GAS DUE TO CHANGES OF PRESSURE AND TEMPERATURE

We have already established the relationship

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

for a given mass of gas.

Let d_1 = density of a gas at pressure P_1 and absolute temperature T_1

and d_2 = density of the gas at pressure P_2 and absolute temperature T_2

Then for mass m of the gas we have:

$$m = V_1 d_1 \text{ and } m = V_2 d_2$$

Hence the above equation becomes:

$$\frac{P_1 m}{d_1 T_1} = \frac{P_2 m}{d_2 T_2} \quad \text{or} \quad \frac{P_1}{d_1 T_1} = \frac{P_2}{d_2 T_2}.$$

Example. The density of air at a pressure of 14.7 lb. per sq. in. and 0° C. is 0.0807 lb. per cub. ft. Find the density of air at the bottom of a mine shaft where the pressure is 15.2 lb. per sq. in. and the temperature 20° C.

From $\frac{P_1}{d_1 T_1} = \frac{P_2}{d_2 T_2}$,
 we have $P_1 = 14.7$ lb. per sq. in.
 $T_1 = 273^\circ$ Abs.
 $d_1 = 0.0807$ lb. per cub. ft.
 $T_2 = 273 + 20^\circ$ Absolute.
 $P_2 = 15.2$ lb. per sq. in.

$$\therefore \frac{14.7}{0.0807 \times 273} = \frac{15.2}{d_2 \times 293}$$

$$\therefore d_2 = \frac{15.2 \times 0.0807 \times 273}{293 \times 14.7} \text{ lb. per cub. ft.}$$

$$= 0.0777 \text{ lb. per cub. ft.}$$

EXERCISES

1. Explain the meaning of temperature, and describe how ordinary temperatures are usually measured. (Min. Sc.; U.L.C.I.)
2. Explain how the coefficient of expansion of a gas at constant pressure may be found. Given that the coefficient of expansion of air at constant pressure is $1/273$ per degree Centigrade, show that the volume of a given mass of air is proportional to the Absolute temperature. (Min. Sc., U.L.C.I.)
3. The temperature of a range of steam pipes, 45 yd. long, varies from 30° F. to 350° F. What will be the increase in length if the coefficient of expansion is 0.000065 per ° F.? Explain how this expansion may be provided for to avoid breakage of the pipes. (Min. Sc.; U.L.C.I.)
4. How does the density of a gas vary with the temperature and with the pressure? If the density of air at 32° F. and at a barometric pressure of 30 in. is 0.08 lb. per cub. ft., what will be the density at a temperature of 83° F. and a barometric pressure of 31.5 in.? (Min. Sc.; U.L.C.I.)
5. At a temperature of 40° F. and a pressure of 15 lb. per sq. in. a mass of air has a volume of 10.63 cub. ft. If the air is compressed to 60 lb. per sq. in. and is then at a temperature of 100° F., what is its volume? (Min. Sc.; U.L.C.I.)
6. An air receiver has a capacity of 40 cub. ft. The gauge pressure of the air in the receiver is 15 lb. per sq. in., and the temperature 60° F. If air is admitted to the receiver until the gauge pressure rises to 80 lb. per sq. in. and the temperature to 100° F., calculate the quantity of air at N.T.P. that has been added. (Min. Sc.; U.L.C.I.)

7. An air compressor draws in 5,000 cub. ft. of air per min. at a temperature of 60° F. and a pressure of 15 lb. per sq. in. absolute. If the discharge pressure is 100 lb. per sq. in. (gauge), and the temperature is 140° F., calculate the volume of compressed air discharged. If before entering the pipe-line the temperature has fallen to 75° F., calculate the volume passing. (Min. Sc.; U.L.C.I.)

8. How may expansion be provided for in a range of steam pipes? If the range is 40 ft. long and the temperature varies between 40° F. and 400° F., what expansion will occur? Coefficient of expansion of iron is 0.0000066 per degree F. (Min. Sc.; U.L.C.I.)

9. The density of air at a temperature of 32° F. and under a pressure of 14.7 lb. per sq. in. is 0.079 lb. per cub. ft. What is the density of the air at the bottom of a mine shaft where the pressure is 15.4 lb. per sq. in. and the temperature 65° F.? (Min. Sc.; U.L.C.I.)

10. A line of cast-iron pipes carries steam to the bottom of a shaft 500 yd. deep. The temperature of the steam is 327° F. When the steam is cut off the temperature of the pipes falls to 72° F. Calculate the contraction of the line of pipes, if the coefficient of linear expansion of cast iron is 0.0000062 per degree F. (Min. Sc.; U.L.C.I.)

11. A pipe range of mild steel is 63.5 ft. long at a temperature of 55° F. What will be the expansion when feed water from an economiser is pumped through it, at a temperature of 260° F.? The coefficient of linear expansion of mild steel is 0.0000066 per degree F. (Min. Sc.; U.L.C.I.)

QUANTITY OF HEAT

75

The examples given above show that:

$$\frac{\text{Quantity of heat gained or lost}}{\text{Weight of water}} = \frac{\text{Change in temperature}}{\text{Change in temperature}}$$

i.e. $H = mt,$

where m is the weight, t the temperature change, and H the heat gained or lost.

SPECIFIC HEAT

Two identical test tubes are chosen. Into one, 50 grams of water are poured, and into the other, 50 grams of paraffin. A Centigrade thermometer is placed in each tube and both tubes are immersed in a water bath, heated by a bunsen burner, at equal distances from the burner.

When the bath is heated, it will be seen that the temperature of the paraffin rises more rapidly than that of the water. Each liquid receives heat at the same rate and the rise in temperature of the paraffin in a given time is greater than that of the water. Hence the quantity of heat to raise the temperature of the paraffin through 1°C. is less than the quantity of heat to raise the temperature of the water 1°C.

So it is with other substances. The quantities of heat required to raise the temperatures of equal weights of various substances through 1°C. are different. Taking water as the standard of reference, we may define the *specific heat of a substance* as the quantity of heat which must be imparted to unit weight of the substance to raise its temperature by one degree compared with the quantity of heat which must be imparted to unit weight of water to raise its temperature by one degree. Thus:

Specific heat of a substance

$$\begin{aligned} &= \frac{\text{Quantity of heat to raise 1 gm. of substance } 1^{\circ}\text{C.}}{\text{Quantity of heat to raise 1 gm. of water } 1^{\circ}\text{C.}} \\ &= \frac{\text{Quantity of heat to raise 1 gm. of substance } 1^{\circ}\text{C.}}{1 \text{ calorie}} \end{aligned}$$

Also the specific heat of a substance

$$= \frac{\text{Quantity of heat to raise 1 lb. of substance } 1^{\circ}\text{F.}}{1 \text{ B.Th.U.}}$$

In each case the units of both numerator and denominator are the same and the value of the specific heat is simply a ratio

which is the same whatever the unit of mass or the scale of temperature may be.

$$\text{i.e.} \quad \text{Specific heat of iron} = \frac{0.11 \text{ B.Th.U.}}{1 \text{ B.Th.U.}} \\ = 0.11$$

$$\text{or} \quad \text{Specific heat of iron} = \frac{0.11 \text{ calorie}}{1 \text{ calorie}} \\ = 0.11$$

The value of a specific heat is sometimes expressed as calories per gram per degree Centigrade or as British Thermal Units per pound per degree Fahrenheit.

$$\text{i.e.} \quad \text{Specific heat of iron} = \frac{0.11 \text{ calorie}}{1 \text{ gram} \times 1 \text{ deg. C.}}$$

Now a calorie is a gram degree Centigrade unit.

$$\text{Hence} \quad \text{Specific heat of iron} = \frac{0.11 \text{ gm.} \times \text{deg. C.}}{1 \text{ gm.} \times 1 \text{ deg. C.}} \\ = 0.11 \text{ (a ratio as before).}$$

$$\text{or} \quad \text{Specific heat of iron} = \frac{0.11 \text{ B.Th.U.}}{1 \text{ lb.} \times 1 \text{ deg. F.}} \\ = \frac{0.11 \text{ lb.} \times \text{deg. F.}}{1 \text{ lb. deg. F.}} \\ = 0.11 \text{ (a ratio).}$$

Example. How much heat must be given to 100 grams of iron in order to raise its temperature through 20°C ? Sp. ht. of iron = $0.11 \text{ cal. per gm. per deg. C.}$

Quantity of heat gained by 1 gm. of water for 1°C . = 1 cal.

Quantity of heat gained by 1 gm. of iron for 1°C . = 0.11 cal.

Quantity of heat gained by 100 gm. of iron for 1°C . = $100 \times 0.11 \text{ cal.}$

Quantity of heat gained by 100 gm. of iron for 20°C . = 100×0.11
 $\times 20 \text{ cal.}$
 $\approx 220 \text{ cal.}$

HEAT GAINED BY m GRAMS OF A SUBSTANCE OF SPECIFIC HEAT s FOR A RISE IN TEMPERATURE OF $t^{\circ}\text{C}$.

Heat gained by 1 gm. of substance for 1°C . rise = s calories

Heat gained by m gm. of substance for 1°C . rise = ms calories

Heat gained by m gm. of substance for $t^{\circ}\text{C}$. rise = mst calories

i.e. Heat gained = Weight \times Specific heat \times Temperature rise.

HEAT LOST BY m LB. OF A SUBSTANCE OF SPECIFIC HEAT s FOR A TEMPERATURE FALL OF t° F.

Heat lost by 1 lb. of substance for 1° F. fall $=s$ B.Th.U.

Heat lost by m lb. of substance for 1° F. fall $=ms$ B.Th.U.

Heat lost by m lb. of substance for t° F. fall $=mst$ B.Th.U.

From the two cases considered above we have in appropriate units:

$$\text{Heat gained or lost} = \text{Weight of substance} \times \text{Specific heat} \times \text{Temperature change}$$

or in symbols $H = mst$

Thermal Capacity

The thermal capacity of a substance is the quantity of heat which must be given to the substance to raise its temperature by one degree.

From $H = mst$, we have:

$$\text{Thermal capacity} = \frac{H}{t} = ms$$

$$\begin{aligned} \text{i.e. Thermal capacity} &= m \text{ (gm.)} \times s \left(\frac{\text{cal.}}{\text{gm.} \times \text{deg. C.}} \right) \\ &= ms \left(\frac{\text{cal.}}{\text{deg. C.}} \right) \end{aligned}$$

$$\text{i.e. Thermal capacity} = \text{weight} \times \text{sp. ht. (cal. per deg. C.)}$$

The thermal capacity of 20 grams of copper, of specific heat 0.094 cal. per gm. per deg. C., is 20×0.094 cal. per deg. C., i.e. 1.88 cal. per deg. C. Also the thermal capacity of 40 lb. of iron, of specific heat 0.11 B.Th.U. per lb. per deg. F., is 40×0.11 B.Th.U. per deg. F., i.e. 4.4 B.Th.U. per deg. F.

Water Equivalent

The water equivalent of a substance is the weight of water which would gain the same quantity of heat as the substance for the same temperature rise.

Let m = weight of substance of specific heat s ,
 t = the temperature increase,
 w = the water equivalent.

Then:

$$\text{Heat gained by water} = \text{Heat gained by substance.}$$

i.e.

$$wt = mst.$$

∴

$$w = ms$$

$$= m \text{ (gm.)} \times s \left(\frac{\text{cal.}}{\text{gm.} \times \text{deg. C.}} \right)$$

$$= ms \left(\frac{\text{cal.}}{\text{deg. C.}} \right)$$

$$= ms \text{ (gm.)}$$

Example. A steel tank weighing 100 lb. contains 500 lb. of water at 15° C. How much heat must be supplied to the tank and contents to raise the temperature to 40° C.? Specific heat of steel = 0.12 C.H.U. per lb. per deg. C.

Water equivalent of tank = 100 × 0.12 lb.

Heat gained by tank = 100 × 0.12 × (40 - 15) C.H.U.
= 300 C.H.U.

Heat gained by water = 500 × (40 - 15) C.H.U.
= 12,500 C.H.U.

∴ Total heat gained = 12,500 C.H.U. + 300 C.H.U.
= 12,800 C.H.U.

METHOD OF MIXTURES

When a quantity of hot water at a temperature t_1 is mixed with a quantity of cold water at a temperature t_2 , the mixture attains some intermediate temperature t_3 . The temperature of the hot water falls from t_1 to t_3 and that of the cold water rises from t_2 to t_3 .

If the heat losses to the surroundings and to the vessel are negligible we have:

Heat lost by hot water = Heat gained by cold water.

If a hot solid is transferred to a quantity of cold liquid contained in a vessel and if we take into account the heat gained by the vessel, we have:

Heat lost by hot solid = Heat gained by cold liquid + Heat gained by cold vessel

again assuming that the heat losses to the surroundings during the mixing are negligible.

• A few examples will illustrate the use of the above formulæ.

Example. A tank contains 100 lb. of water at 60° F. What weight of water at a temperature of 180° F. must be run into the tank in order to

raise the temperature of the water to 100°F. , assuming no heat losses to the tank and surroundings.

Let m = weight of hot water at 180°F.

$$\begin{aligned}\text{Heat lost by hot water} &= m(180 - 100) \text{ B.Th.U.} \\ &= 80m \text{ B.Th.U.}\end{aligned}$$

$$\begin{aligned}\text{Heat gained by cold water} &= 100 \times (100 - 60) \text{ B.Th.U.} \\ &= 4,000 \text{ B.Th.U.}\end{aligned}$$

$$\text{Hence } 80m \text{ B.Th.U.} = 4,000 \text{ B.Th.U.}$$

$$\begin{aligned}\therefore m &= \frac{4,000}{80} \text{ lb.} \\ &= 50 \text{ lb.}\end{aligned}$$

Example. An iron ball weighing 0.5 lb. is transferred from a furnace into an iron vessel weighing 1.2 lb. and containing 2.5 lb. of water at 15°C. The temperature of the vessel and contents rises to 35°C. If the specific heat of iron is $0.1 \text{ C.H.U. per lb. per deg. C.}$ and assuming that no heat is lost to the surroundings, calculate the temperature of the furnace.

Let t = the temperature of the furnace.

$$\begin{aligned}\text{Heat lost by iron ball} &= \text{weight} \times \text{sp. ht.} \times \text{temp. fall.} \\ &= 0.5 \times 0.1 \times (t - 35) \text{ C.H.U.}\end{aligned}$$

$$\text{Heat gained by water} = 2.5 \times (35 - 15) \text{ C.H.U.}$$

$$\text{Heat gained by iron vessel} = 1.2 \times 0.1 \times (35 - 15) \text{ C.H.U.}$$

Hence:

$$0.5 \times 0.1 \times (t - 35) = 2.5 \times (35 - 15) + 1.2 \times 0.1 \times (35 - 15).$$

$$\text{i.e. } 0.05 \times (t - 35) = 50 + 2.4$$

$$\begin{aligned}\therefore t - 35 &= \frac{52.4}{0.05} \\ &= 1,048\end{aligned}$$

$$\begin{aligned}\therefore t &= 1,048 + 35 \\ &= 1,083^{\circ}\text{C.}\end{aligned}$$

Determination of the Specific Heat of a Solid by Method of Mixtures

Fig. 61 shows a double calorimeter, which consists of a small copper vessel surrounded by a large vessel, the space between being packed with cotton wool. This arrangement reduces the heat losses from the inner calorimeter to the surroundings to a minimum.

To perform an experiment the inner calorimeter is weighed empty and then containing a quantity of water. A piece of aluminium which has been previously weighed is heated to 100°C. , by suspending it for a few minutes from a piece of cotton thread in a beaker containing boiling water. The tempera-

ture of the boiling water and the initial temperature of the water in the calorimeter are noted. The piece of aluminium is then transferred to the calorimeter and, after stirring, the final temperature of the mixture is noted. A set of results is shown below:

Weight of calorimeter	=40.1 gm.
Weight of calorimeter + water	=141.8 gm.
Weight of aluminium	=32.5 gm.
Initial temperature of water in calorimeter	=15° C.
Initial temperature of aluminium	=100° C.
Final temperature of mixture	=20° C.
Specific heat of copper	=0.1

Let x = Specific heat of aluminium.

Heat lost by solid, i.e. aluminium
 $= 32.5 \times x \times (100 - 20)$ cal.

Heat gained by water
 $= 101.7 \times (20 - 15)$ cal.

Heat gained by calorimeter
 $= 40.1 \times 0.1 \times (20 - 15)$ cal.

Hence $32.5 \times x \times (100 - 20)$
 $= 101.7 \times (20 - 15) + 40.1 \times 0.1 \times (20 - 15),$

i.e. $2,600 x = 508.5 + 20.05$
 $= 528.55$

$\therefore x = \frac{528.55}{2,600}$
 $= 0.20$ cal. per gm. per deg. C.

N.B. A small amount of hot water is transferred from the beaker to the weighed calorimeter, but this does not materially affect the result.

CALORIFIC VALUE

It is a well-known fact that fuels such as coal, paraffin, town gas, etc., give out heat when burned. Also one fuel may give out more heat than an equal weight of another fuel. This leads to the idea of the *calorific value of a fuel*, which may be defined as *the quantity of heat given out by the complete combustion of unit weight of the fuel*. Thus the calorific value of a given sample of coal may be stated as 13,500 B.Th.U. per lb.

The following table gives the calorific values of various types of bituminous coals mined in the Wigan area.

Type	Calorific Value (B.Th.U per lb.)	Where found
Non-coking . .	13,850-14,400	Upper seams
Slightly coking . .	14,400-14,670	Seams such as Florida
Medium coking . .	14,670-15,030	Wigan 6 ft. and mines below
Strong coking . .	15,030-15,660	Arley

In the case of town gas, the calorific value may be defined as the quantity of heat given out by the complete combustion of 1 cubic foot of the gas at 0° C. and 14.7 lb. per sq. in. absolute pressure. Gas is generally manufactured so that its calorific value is 480 B.Th.U. per cubic foot and this is the usual standard of quality.

THE BOMB CALORIMETER

An apparatus used for the determination of the calorific value of a fuel, such as coal, is the bomb calorimeter (Fig. 62). The steel vessel A, known as the bomb, is provided with a steel cap B which can be screwed on to it. The cap is provided with a steel tube through which oxygen can be admitted from the branch tube D by turning the screw C. The supply of oxygen ensures complete combustion of the fuel. A crucible G, containing a weighed quantity of the fuel, is suspended by wires which are attached to the terminals E and F. These wires serve as leads to the ignition wire I which passes through the fuel.

The bomb rests on supports in a calorimeter H which contains a quantity of water and the water is stirred by the stirrer J. The calorimeter is enclosed in an outer vessel, the space between them being packed with cotton wool to minimise the heat losses to the surroundings.

To perform an experiment, a weighed quantity of the fuel is placed in the crucible and the steel cap is then screwed on the bomb. A quantity of oxygen is admitted and the circuit containing the ignition wire is completed (see Ch. XI). The electric current raises the wire to incandescence and the fuel is ignited.

The initial temperature of the calorimeter and contents having been noted, the water is stirred until the heat produced by the combustion of the fuel raises the temperature to a final steady value. Since the water equivalent of the calorimeter

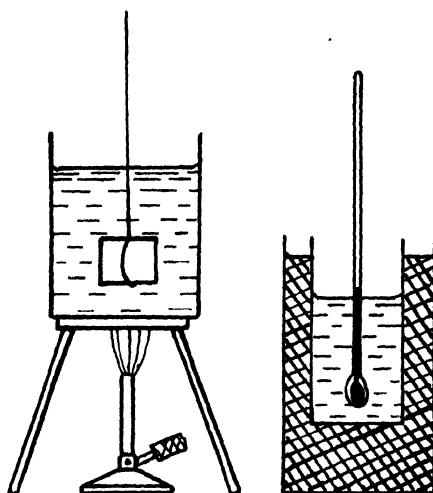


FIG.61

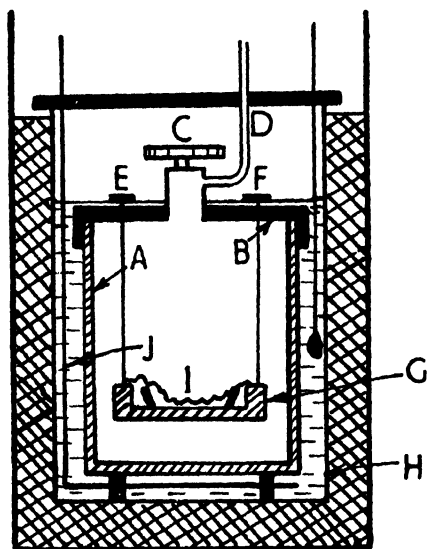


FIG.62

and contents is known, the calorific value of the fuel may be determined as follows:

Weight of fuel	=1.2 gm.
Weight of water in calorimeter	=2,340 gm.
Water equivalent of calorimeter	=320 gm.
Initial temperature of water	=17.5° C.
Final temperature of water	=20.7° C.
Heat gained by water	=2,340 × 3.2 cal.
Heat gained by calorimeter	=320 × 3.2 cal.
Total heat gained	=2,660 × 3.2 cal.

Heat produced by the burn-
ing of 1.2 gm. of fuel = 2,660 × 3.2 cal.

$$\therefore \text{Calorific value of the fuel} = \frac{2,660 \times 3.2}{1.2} \text{ cal. per gm.}$$

$$= 7,093 \text{ cal. per gm.}$$

EXERCISES

1. Explain clearly, the meaning of (a) the unit of heat, (b) Specific Heat, (c) Latent Heat. How does the specific heat of a liquid compare with that of a solid? Give one example of how the high specific heat of a substance has a practical value. (Min. Sc.; U.L.C.I.)

2. Define the following terms: Calorie; British Thermal Unit; Specific Heat. Describe fully, how the specific heat of a solid substance may be determined. (Min. Sc.; U.L.C.I.)

3. A metal tank weighs 50 lb. and contains 9 gallons of oil with a specific gravity of 0.78. The temperature of the oil rises from 50° F. to 80° F. in 3 min. What quantity of heat has been added per min.? The specific heat of the metal is 0.12, and that of the oil 0.52. (Min. Sc.; U.L.C.I.)

4. Define (a) the Centigrade heat unit, and (b) specific heat. Steam from an engine is condensed by water flowing through a condenser. If 500,000 B.Th.U. are taken from the steam per hour and the inlet and outlet temperatures of the circulating water are 60° F. and 105° F. respectively, find the weight of water flowing through the condenser per minute. (Min. Sc.; U.L.C.I.)

5. In an experiment to determine the specific heat of a metal, 155 gm. of the substance was heated to 100° C. and then placed in 100 gm. of water in a calorimeter whose water equivalent was 8.5 gm. The initial temperature of the water was 18° C., and the final temperature was 21.5° C. Calculate the specific heat of the metal. (Min. Sc.; U.L.C.I.)

6. A piece of copper of weight 2.5 lb. is allowed to remain in a current of hot gases in a flue for a considerable time. It is then transferred to a copper vessel weighing 3 lb. and containing 20 lb. of water at 15° C. and the temperature rises to 20° C. Assuming the specific heat of copper

to be 0.093 C.H.U. per lb. per deg. C., determine the temperature of the flue gases.

7. The heat produced by the burning of 3.5 gm. of coal is passed into a vessel of water equivalent 200 gm. and containing 5,200 gm. of water at 17° C. The temperature of the water rises to 21.5° C. Find how much heat is generated by the burning of 1 gm. of coal.

CHAPTER VIII

CHANGE OF STATE

LATENT HEAT

If a beaker containing a mixture of ice and water is placed on a tripod, fitted with a sheet of gauze, and the beaker and contents are heated by means of a bunsen burner, it will be found that the temperature remains at $0^{\circ}\text{C}.$ so long as any ice is left unmelted and provided that the mixture is well stirred. If the heating is continued when all the ice is melted, the temperature of the water increases until boiling point is reached and the temperature again remains constant. If, during the experiment, the temperature is noted every minute, a set of results like the following is obtained.

Temp. ($^{\circ}\text{C}.$)	0	0	0	0	14	26	39	51	62	75	87	100	100	100	100	100
Time (Minutes)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

In the graph shown in Fig. 63, AB represents the change of state from ice to water, BC the rise in temperature of the water with time, and CD the change of state from water to steam. The point B represents the instant when all the ice has melted and the point C represents the instant when boiling commences. The heat supplied during the operation AB is termed latent heat of fusion while the heat supplied during the operation CD is known as latent heat of vaporisation. During a change of state it will be seen that the temperature remains constant. Thus *latent heat* may be defined as *the heat which must be imparted to or withdrawn from a substance to change its state at constant temperature*. The line BC represents the rise in temperature of the water with time and the heat supplied in this operation is called *sensible heat*, which may be defined as *the heat which must be given to or withdrawn from a substance to change its temperature without change of state*.

Melting Point

The melting point of a substance is the temperature at which the substance changes from the solid to the liquid state.

Freezing Point

The freezing point of a substance is the temperature at which the substance changes from the liquid to the solid state.

Melting point and freezing point are the same temperature for any particular substance, the difference being that at melting point heat is supplied to the substance whereas at freezing point heat is withdrawn from the substance.

$$\begin{array}{l} \text{Thus:} \quad \text{Solid at Melting Point} + \text{Latent Heat of Fusion} \rightarrow \text{Liquid} \\ \text{and} \quad \text{Liquid at Freezing Point} - \text{Latent Heat of Fusion} \rightarrow \text{Solid.} \end{array}$$

Boiling Point

At this stage we may consider the boiling point of a liquid as the temperature at which a liquid boils, that is the temperature at which bubbles of vapour appear at all points of the liquid.

Condensation Point

The condensation point of a vapour is the temperature at which the vapour changes into its liquid state.

$$\begin{array}{l} \text{Thus:} \quad \text{Liquid at Boiling Point} + \text{Latent Heat of Vaporisation} \rightarrow \text{Gas or vapour} \\ \text{and} \quad \text{Gas or vapour at Condensation Point} - \text{Latent Heat of Vaporisation} \rightarrow \text{Liquid.} \end{array}$$

LATENT HEATS OF FUSION AND VAPORISATION

The *Latent Heat of Fusion* of a substance is the quantity of heat which must be imparted to unit weight of the substance to completely change it from the solid to the liquid state at constant temperature.

The latent heat of fusion of ice is 80 calories per gram, 80 Centigrade Heat Units per lb. or $\frac{2}{5} \times 80$, i.e. 144 British Thermal Units per lb.

The *Latent Heat of Vaporisation* of a liquid is the quantity of heat which must be given to unit weight of the liquid to completely change it into the gaseous state at constant temperature, i.e. boiling point.

The latent heat of vaporisation of water or the latent heat of steam is 540 calories per gram, 540 Centigrade Heat Units per lb. or $\frac{2}{5} \times 540$, i.e. 972 British Thermal Units per lb.

Example. Feed water at 60° F. is supplied to a boiler. How much heat is required to convert 2,000 lb. of this water into steam at 212° F.?

$$\text{Sensible heat gained by water} = 2,000 \times (212 - 60) \text{ B.Th.U.} \\ = 304,000 \text{ B.Th.U.}$$

$$\text{Latent heat gained} = 2,000 \times 972 \text{ B.Th.U.} \\ = 1,944,000 \text{ B.Th.U.}$$

$$\text{Full quantity of heat gained} = 304,000 + 1,944,000 \text{ B.Th.U.} \\ = 2,248,000 \text{ B.Th.U.}$$

THE MIXING OF STEAM AND WATER

When steam is passed into cold water contained in a vessel, a final common temperature is attained. Thus if no heat is lost to the surroundings during the mixing we have:

$$\begin{array}{ccccccc} \text{Heat lost by} & & \text{Heat lost} & & \text{Heat gained} & & \text{Heat} \\ \text{steam in} & + & \text{by water} & = & \text{by cold} & + & \text{gained by} \\ \text{condensing} & & \text{formed} & & \text{water} & & \text{vessel} \end{array}$$

Example. A copper tank weighs 20 lb. and contains 150 lb. of water at 15° C. How much steam generated at 100° C. must be passed into the water in order to raise the temperature of the vessel and water to 25° C.? Latent heat of steam = 540 C.H.U. per lb.; specific heat of copper = 0.093 C.H.U. per lb. per deg. C.

Let w = weight of steam in lbs.

$$\text{Heat lost by steam in condensing} = 540w \text{ C.H.U.}$$

$$\text{Heat lost by water formed} = w(100 - 25) \text{ C.H.U.}$$

$$\text{Heat gained by cold water} = 150 \times (25 - 15) \text{ C.H.U.}$$

$$\text{Heat gained by vessel} = 20 \times 0.093 \times (25 - 15) \text{ C.H.U.}$$

$$\therefore 540w + 75w = 150 \times 10 + 20 \times 0.093 \times 10$$

$$\therefore 615w = 1,500 + 18.6$$

$$\therefore w = \frac{1,518.6}{615}$$

$$= 2.47 \text{ lb. of steam.}$$

Determination of the Latent Heat of Steam by Method of Mixtures

The experiment is carried out in the following manner. A small copper calorimeter is weighed empty and then about two-thirds filled with water. The calorimeter is placed in an outer vessel and the space between the two vessels is packed with cotton wool, which reduces the heat losses to the surroundings during the passing of the steam to a minimum.

Fig. 64 shows the steam-generating plant with the steam-drying tube B, connected to the boiler A. The steam is allowed

to pass for a few minutes before it is used in order to allow the temperature of the apparatus to reach 100°C . There is then no tendency for the steam to condense in the delivery tubes. The

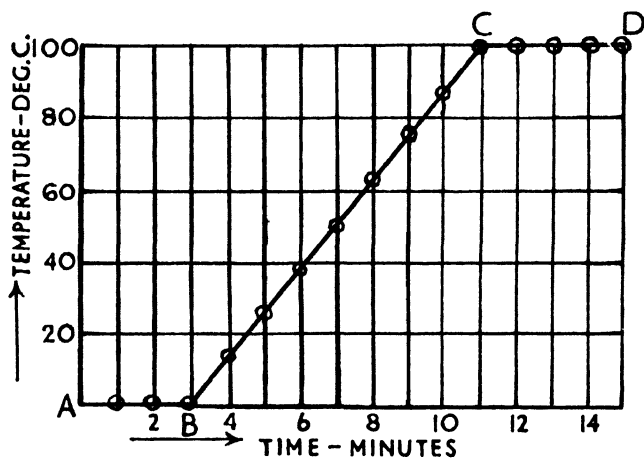


FIG. 63

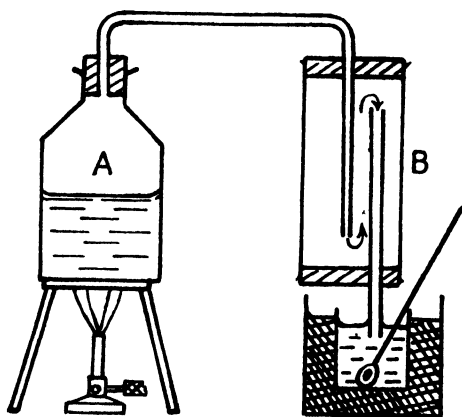


FIG. 64

temperature of the water in the calorimeter is noted and the end of the delivery tube is immersed in the water until a temperature of about 50°C . is reached. This final temperature

and the weight of the calorimeter and contents are noted. A set of results is shown below.

Weight of calorimeter	=43.56 gm.
Weight of calorimeter + water	=148.43 gm.
Weight of calorimeter + water + steam	=154.71 gm.
Initial temperature of water	=15° C.
Final temperature of mixture	=49° C.
Temperature of steam	=100° C.
Specific heat of copper	=0.1 cal. per gm. per deg. C.

Let L = latent heat of steam.

Heat lost by steam in condensing = $6.28L$ cal.

Heat lost by water formed = $6.28 \times (100 - 49)$ cal.

Heat gained by water in calorimeter = $104.87 \times (49 - 15)$ cal.

Heat gained by calorimeter = $43.56 \times 0.1 \times (49 - 15)$ cal.

$$\therefore 6.28L + 6.28 \times (100 - 49) = 104.87 \times (49 - 15) + 43.56 \times 0.1 \times (49 - 15)$$

$$\therefore 6.28L + 320.28 = 3,565.58 + 148.10$$

$$\therefore L = 540 \text{ cal. per gm.}$$

EVAPORATION

If a dish containing water is left for some time, the water ultimately disappears and changes into water vapour. The molecules of the water are in continual motion and some of them break through the surface and escape into the air above, becoming water vapour. This process continues until all the water disappears.

Thus there are two processes by which a liquid changes into a vapour, (1) by actual boiling, or ebullition as it is sometimes called, and (2) by evaporation.

Boiling takes place at one temperature only, for any particular atmospheric pressure, whereas evaporation takes place at all temperatures. In both cases latent heat of vaporisation must be imparted to the liquid to effect the change of state. In the case of boiling, the heat is derived from external sources, whereas in evaporation the heat is taken from the liquid itself, thus causing the liquid to cool.

The rate of evaporation depends on the area of the surface of the liquid. The greater the surface area, the greater is the rate

of evaporation. The quantity of vapour already present in the space above the liquid has also an effect on the rate of evaporation. Thus the drier the air above a water surface the greater is the rate of evaporation. But, if the air is saturated no evaporation takes place. It is therefore obvious that air currents increase the rate of evaporation, for if the air is motionless saturation conditions will soon be attained. Air currents remove the saturated air and supply fresh dry air to the surface. This allows evaporation to continue.

REFRIGERATION

Refrigeration is the term applied to the artificial freezing of a liquid, generally the freezing of water. The following experiment illustrates refrigeration.

A few drops of water are poured on a wooden block A and a copper vessel B containing ether is placed on the water (Fig. 65). If air is blown through the ether by means of a piece of tubing C, connected to the bellows, the vessel will be frozen on to the block of wood.

Ether is a very volatile liquid, that is, a liquid which readily changes into a vapour. The process of blowing air through the ether brings more air into contact with the liquid and increases the rate of evaporation. Heat is required for vaporisation and some of this heat is taken from the water underneath the vessel. The water cools to 0°C . and then freezes.

VAPOUR PRESSURE

When a mercurial barometer is set up as in Fig. 66a, the space above the mercury column is a vacuum. If a drop of ether is inserted through the bottom of the tube by means of a bent pipette, the ether rises to the space above, vaporises and the column of mercury is depressed. If all the ether vaporises, the space above the mercury column contains unsaturated ether vapour (Fig. 66b). If the addition of the ether is continued, a stage is reached when a thin film of liquid ether remains on the top of the mercury column and at this stage the ether vapour is saturated (Fig. 66c).

The saturation vapour pressure of the ether is given by

$$P = B - H,$$

where B = the barometric height in cm.

H = the height of the mercury column in cm.

and P = the saturation vapour pressure of the ether in cm.
of mercury at the temperature of the experiment.

Saturated and Unsaturated Vapours

The above experiment illustrates the difference between a saturated and an unsaturated vapour. In the case of a saturated

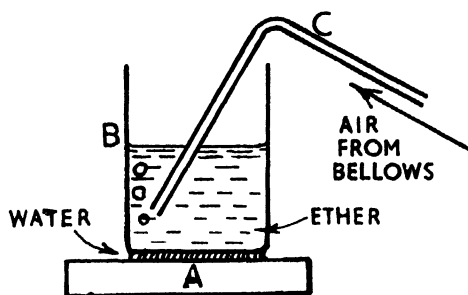


FIG. 65

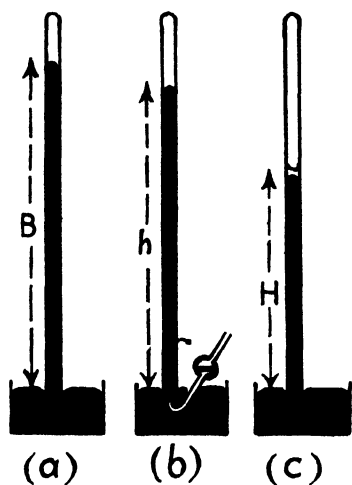


FIG. 66

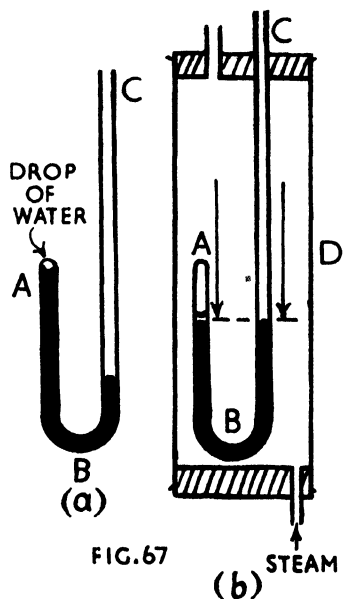


FIG. 67

vapour there is excess of liquid in contact with the vapour, whereas in the case of an unsaturated vapour there is no excess of liquid. Again, in the unsaturated vapour state (Fig. 66b), as

more and more liquid is added, the mercury column is depressed more and more; but when the vapour becomes saturated further addition of liquid has little effect on the height of the mercury column. This shows that a vapour in the saturated state exerts its maximum vapour pressure.

Boiling Point of a Liquid

We are now in a position to examine more closely what is meant by the boiling point of a liquid. Fig. 67a shows a U-tube ABC, the shorter branch of which is closed at A and the longer branch open to the atmosphere. The tube contains a quantity of mercury and a drop of water. By inverting the tube a few times, the air in the branch AB can be withdrawn and the mercury rises to fill this branch, leaving the drop of water trapped at the end A. If the U-tube is now placed in a steam jacket D and steam is passed round the tube for a few minutes, the mercury in both branches attains the same level. A small drop of water is left in contact with the saturated water vapour in AB (Fig. 67b).

Thus: $\begin{array}{l} \text{Saturation Vapour Pressure} \\ \text{of water at } 100^{\circ} \text{ C.} \end{array} = \text{Atmospheric Pressure.}$

But the water from which the steam is produced is boiling at 100° C.

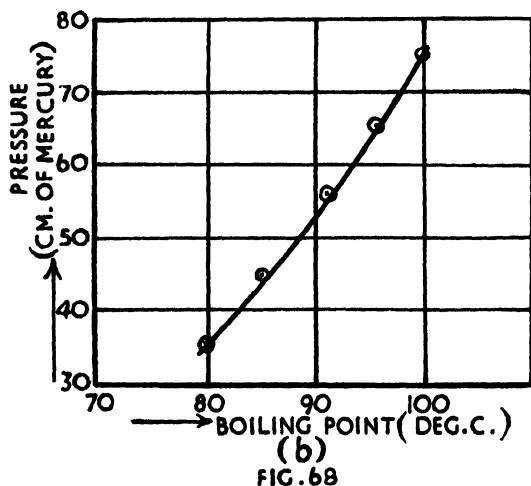
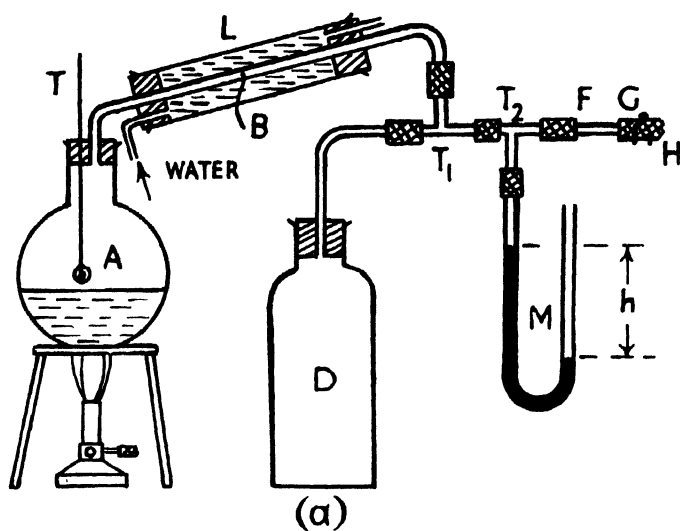
Hence: $\begin{array}{l} \text{Saturation Vapour Pressure} \\ \text{of water at Boiling Point} \end{array} = \text{Atmospheric Pressure.}$

We are thus led to the conclusion that water boils at the temperature for which its saturation vapour pressure is equal to the atmospheric pressure. But the pressure on the surface of water or any other liquid may be varied by pumping air into or withdrawing air from the boiling flask and, in each case, the liquid boils at the temperature for which its saturation vapour pressure is equal to the pressure on its surface.

Determination of the Boiling Point of Water under Different Pressures

The apparatus used for determining the boiling point of water at different pressures is shown in Fig. 68a. The boiling flask A which is closed by a stopper contains a quantity of water and rests on a tripod. A thermometer T and one end of the delivery tube B pass through the stopper and the delivery tube is surrounded by a Liebig's condenser L through which cold water from the tap circulates. The other end of the delivery tube is

connected by pressure tubing to one branch of a glass T-piece T_1 . The other two branches of the T-piece T_1 are connected through pressure tubing, one to a large winchester D and the



other to a branch of a second T-piece T_2 . The other branches of this T-piece are connected through pressure tubing, one to the manometer M which contains mercury and the other to the

glass tube FG. A piece of pressure tubing, closed by a clip H is attached to the end G of the tube FG.

It is essential that all the joints of the apparatus should be airtight. If not, they should be sealed with vacuum grease. The function of the winchester D is to supply a large volume of air to the apparatus so as to prevent fluctuations of pressure.

In performing an experiment, the clip H is released and a vacuum pump is attached to the tube FG. The pressure of the air inside the apparatus is reduced to about 30 cm. of mercury and the water in the flask is heated until boiling commences. The thermometer T is read along with the difference in the mercury levels of the manometer. A little air is then admitted into the apparatus by removing the pump, slightly releasing the clip H and then closing it again. The boiling point and the manometer reading are again noted. This process is repeated until the pressure of the air in the apparatus becomes equal to that of the atmosphere.

A compression pump is now applied to the end of the tube FG and the observations of boiling point and pressure are again repeated. A table of results is shown below and a graph connecting boiling point and pressure is shown in Fig. 68b.

Barometric Pressure B (cm. of mercury)	Excess Pressure h (cm.)	Total Pressure $B+h$ (cm.)	Temperature, B. Pt ° C.
76.0	0	76.0	100
76.0	10.3	65.7	96
76.0	19.3	56.7	92
76.0	31.5	44.5	85
76.0	40.5	35.5	80

The Steam in an Engine Boiler

When water is heated in an engine boiler, steam is given off and in the confined space above the water its pressure increases. Thus the pressure on the surface of the water increases with a consequent increase in the boiling point. This process continues until the supply pressure is reached, when the steam enters the engine cylinder.

MOISTURE IN THE ATMOSPHERE.—DEW POINT

If a glass tumbler containing cold water is brought into a warm room it will be noticed that water collects on the outside of the tumbler. The cold surface cools the air near it and water is deposited on the surface.

Evidently the atmosphere contains a certain quantity of invisible water vapour and during cooling water is deposited when a certain temperature is reached. This temperature is known as the dew point and at this temperature the air is saturated with water vapour. Thus we may define *dew point* as the temperature at which the quantity of water vapour actually present in a given volume of air is sufficient to saturate this volume and condensation commences.

The following table gives the weight of water vapour in one cubic foot of a saturated atmosphere at various temperatures.

Temperature	Wt. of water vapour per cub. ft. of air
32° F.	0.00031 lb
40° F.	0.00041 lb.
60° F.	0.00084 lb.
80° F.	0.00157 lb.

The above table shows that the weight of water vapour to saturate one cubic foot of air increases with the temperature.

RELATIVE HUMIDITY

We are now in a position to consider the quantity of water vapour actually present in a given volume of air compared with the quantity of water vapour required to saturate this volume of air. This ratio is known as the relative humidity of the atmosphere.

Thus: Relative Humidity (R.H.)

$$= \frac{\text{Weight of water vapour actually present per cub. ft. of air}}{\text{Weight of water vapour to saturate 1 cub. ft. of air at the same temperature.}}$$

The Wet- and Dry-bulb Hygrometer

The wet- and dry-bulb hygrometer (Fig. 69) consists of two mercurial thermometers A and B. The thermometer A has its bulb uncovered and registers the temperature of the air. The thermometer B has its bulb covered with a strip of muslin which also dips into a small vessel C, containing water. Water rises continuously up the muslin and keeps the bulb of the thermometer wet. Since evaporation takes place and the heat required for this evaporation is taken from the bulb the temperature of the wet bulb is generally lower than that of the dry bulb. When, however, the air is saturated with water vapour,

no evaporation takes place and the temperatures of the bulbs are the same.

To find the relative humidity of the atmosphere the readings of the wet and dry bulbs are noted and the relative humidity is read off directly from the hygrometer table shown below.

Tempera- ture of Dry Bulb	Difference of Temperature between Wet and Dry Bulbs – Relative Humidity (per cent.)												
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°
32° F.	100	87	76	65	56	48	41	35	30	27	23	19	16
36° F.	100	91	82	74	66	59	53	47	42	38	34	30	27
40° F.	100	92	84	76	70	63	58	52	47	43	38	34	31
44° F.	100	92	84	78	72	65	60	55	50	46	41	38	34
48° F.	100	92	85	79	73	67	62	57	52	48	44	40	36
52° F.	100	93	86	80	74	69	63	59	54	50	46	43	39
56° F.	100	93	87	81	75	70	65	60	56	52	48	45	41
60° F.	100	93	88	82	76	71	66	62	58	54	50	46	43
64° F.	100	94	88	82	77	72	68	63	59	55	52	48	45
68° F.	100	94	88	83	78	73	69	65	60	56	53	50	46
70° F.	100	94	89	83	78	74	69	65	61	57	54	50	47
80° F.	100	95	90	85	80	76	72	67	64	60	57	53	50

A whirling hygrometer used in mining is shown in Fig. 70. The instrument is held in the hand and whirled about the handle. In this way the bulbs are in contact with a greater volume of air and a more representative result is obtained.

Example. In a mine, the air entering the downcast shaft shows a dry-bulb reading of 40° F. and a wet-bulb reading of 34° F. The air leaving the upcast shaft shows a dry-bulb reading of 60° F. and a wet-bulb reading of 57° F. If 80,000 cub. ft. of air is circulated per minute, what weight of water is taken up by the circulating air per hour?

From tables R.H. of air entering downcast shaft = 0.58

Weight of water vapour to saturate 1 cub. ft. of air at 40° F. = 0.00041 lb.

$$\therefore \text{Wt. of water vapour actually present per cub. ft.} = 0.00041 \times \frac{58}{100} \text{ lb.} \\ = 0.000238 \text{ lb.}$$

From tables R.H. of air leaving upcast shaft = 0.82.

Weight of water vapour to saturate 1 cub. ft. of air at 60° F. = 0.00084 lb.

$$\therefore \text{Wt. of water vapour actually present per cub. ft.} = 0.00084 \times \frac{82}{100} \text{ lb.} \\ = 0.000689 \text{ lb.}$$

$$\therefore \text{Wt. of water taken up by 1 cub. ft. of air} = 0.000689 \text{ lb.} \\ = 0.000238 \text{ lb.} \\ = 0.000451 \text{ lb.}$$

$$\therefore \text{Wt. of water taken up by 80,000 cub. ft. of air} = 80,000 \times 0.000451 \text{ lb.} \\ = 36.08 \text{ lb.}$$

$$\therefore \text{Wt. of water taken up per hour} = 60 \times 36.08 \text{ lb.} \\ = 2,165 \text{ lb.}$$

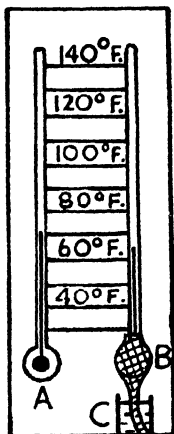


FIG.69

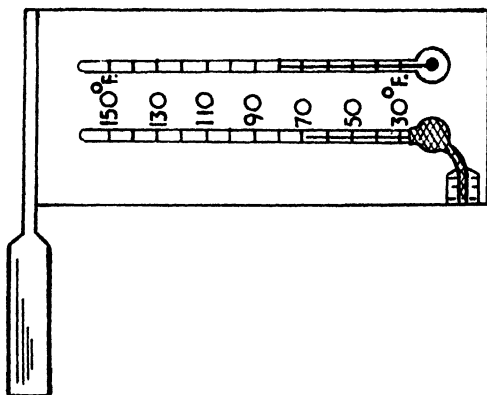


FIG.70

HYGROMETRY AND MINE AIR

The condition of the atmosphere with regard to the amount of moisture it contains affects the health of the miner. The human body gives off moisture, organic acids, etc., in the form of perspiration and it is partly due to this that the temperature of the body is prevented from rising.

When the difference between the readings of the wet and dry bulbs is considerable the atmosphere is moderately dry, and

evaporation of the miner's perspiration proceeds at a good rate. But when the difference in the readings is small, the atmosphere is near its saturation point and in this case it is difficult for evaporation and removal of perspiration to take place. Thus the cooling of the body which always accompanies evaporation is retarded, the blood becomes overheated and the miner suffers from heat stroke.

There are other important aspects of the relative humidity of mine air. When the air is dry there is a greater possibility of coal dust explosions. In wet mines, however, where there is excess of moisture, the danger of coal dust explosions does not exist.

One of the indications of gob fires is the "sweating" of the strata. This is due to the condensation of the water vapour, produced during the burning of the coal, on the floor, roof and sides of the roadways. The relative humidity of the air in the return airway in this case is considerable and is an indication of "sweating." Under these conditions the management has to take immediate action.

EXERCISES

1. What is meant by the terms (a) Specific Heat, and (b) Latent Heat? What weight of steam at 212° F. must be passed into 3,000 lb. of water at a temperature of 60° F. and contained in a steel tank weighing 200 lb., so that the temperature of the water and tank rises to 90° F.? The specific heat of steel is 0.11 B.Th.U. per lb. per deg. F. and the latent heat of steam at 212° F. is 970 B.Th.U. per lb.

(Min. Sc.; U.L.C.I.)

2. Define relative humidity. Describe the wet- and dry-bulb hygrometer, and explain how you would use it for finding the relative humidity of the air at the bottom of a mine shaft. Why, in general, is the reading of the wet bulb lower than that of the dry bulb?

(Min. Sc., U.L.C.I.)

3. Explain the terms "Relative Humidity," "Dew Point" and "Vapour Pressure." How may the relative humidity of mine air be determined?

(Min. Sc.; U.L.C.I.)

4. Why are the readings of a hygrometer of interest to the miner? At one coal face the wet- and dry-bulb readings are 65° F. and 70° F. respectively. At another face, the readings are 68° F. and 70° F. respectively. At which face does the air contain the more moisture and why?

(Min. Sc.; U.E.I.)

5. What is meant by (a) "unit of heat," and (b) "specific heat"?

What amount of heat will be required to convert 250 lb. of water at 60° F. into steam at 212° F.? The latent heat of steam is 966 B.Th.U. per lb.

(Min. Sc.; U.L.C.I.)

6. What is meant by "Relative Humidity"? Describe how the humidity of mine air varies in the passage of the air from the surface through

the downcast shaft, the intake airways, the working places, the return airways, and finally through the upcast to the surface. Explain fully how these variations in humidity are caused. (Min. Sc.; U.L.C.I.)

7. A tank contains 100 lb. of water at 60° F. Steam at atmospheric pressure is fed into the tank until the temperature rises to 100° F. If the tank has a water equivalent of 20 lb., calculate the quantity of steam which has been added (a) if the steam is dry, and (b) if the steam has a dryness fraction of 0.88. The latent heat of steam at atmospheric pressure is 970 B.Th.U. per lb. (Min. Sc.; U.L.C.I.)

8. Under what circumstances will the reading of the wet-bulb thermometer of a hygrometer be lower than the reading of the dry-bulb thermometer? Explain, fully, why the readings of a hygrometer are of interest to the miner. (Min. Sc.; U.L.C.I.)

9. Describe the construction and use of a wet- and dry-bulb hygrometer. What difference in reading would you expect to find if a hygrometer were carried from the bottom of the downcast shaft to the bottom of the upcast shaft? Explain the cause of the difference. (Min. Sc.; U.L.C.I.)

10. Define (a) British Thermal Unit, and (b) Latent Heat of Vaporisation.

Steam at 212° F. passes through a condenser at the rate of 250 lb. an hour, and the condensed water leaves the condenser at a temperature of 80° F. How much heat is withdrawn from the steam by the condenser per minute? Latent heat of steam at 212° F. = 970 B.Th.U. per lb. (Min. Sc.; U.L.C.I.)

11. Define (a) Specific Heat, and (b) Latent Heat of Vaporisation.

A steel boiler, weighing 200 lb., contains 1,000 lb. of water at 60° F. How much heat, assuming no losses due to radiation, must be imparted to the boiler and its contents to convert 250 lb. of the water into steam at 212° F.? Latent heat of steam at 212° F. = 970 B.Th.U. per lb. Specific heat of steel = 0.11 B.Th.U. per lb. per deg. F. (Min. Sc.; U.L.C.I.)

CHAPTER IX

MECHANICAL EQUIVALENT OF HEAT

ENERGY

We have already seen (Ch. VII) that fuels such as coal, paraffin, petrol, etc., when burned give out heat. In the case of the combustion of the coal in an engine furnace, the heat produced raises the temperature of the water in the boiler to boiling point and converts some of it into steam. The steam under pressure enters the cylinder and on expansion performs the work required to drive the piston. The motion of the piston is transmitted to the connecting-rod and thence to the flywheel. Thus heat is transformed into work and then into energy of motion, which is known as kinetic energy.

Again, in the petrol engine which is known as an internal-combustion engine because the petrol vapour is ignited in the cylinder, the heat produced by the ignition of the petrol vapour produces sudden expansion of the gaseous products of combustion. The piston is driven along the cylinder and its energy of motion is transmitted to the connecting-rod, flywheel, etc. As in the steam engine heat is transformed into work and then into kinetic energy.

Kinetic Energy

Kinetic energy is the energy a body possesses by virtue of its motion, and it is measured in the same units as work, that is, in foot-pounds in the English system or in ergs in the Centimetre Gram system of units.

Potential Energy

In the case of a reservoir on the top of a hill, if the water is allowed to descend to a lower level it gains energy of motion or kinetic energy, which may be transmitted to a water wheel. Before the water is released it possesses energy due to its position, which is known as potential energy. Potential energy is stored-up energy and only requires releasing in order to be transformed into kinetic energy. Thus we see that heat, work and kinetic and potential energies are all forms of energy

and any one form may be converted into other forms of energy.

PRINCIPLE OF THE CONSERVATION OF ENERGY

Energy can neither be created nor destroyed but it can be transformed from one form into another. The quantity of heat produced by the combustion of the coal in the engine furnace depends on the quantity of energy in the coal, and the work done by the expansion of the steam in the engine cylinder depends

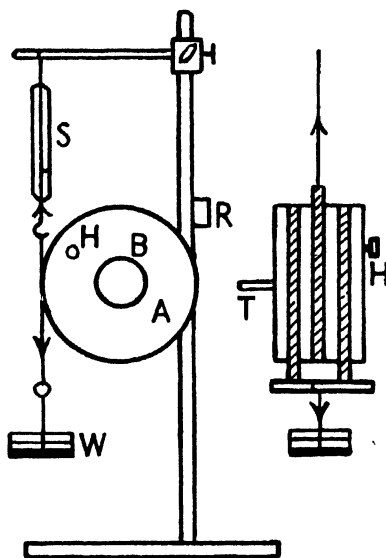


FIG. 71

on the quantity of heat lost by the steam. Also the work expended against the force of friction in a machine appears in the form of heat, and the quantity of heat produced depends on the amount of work expended. Actually a definite relationship exists between the work expended and the quantity of heat which appears. This relationship will now be discussed.

MECHANICAL EQUIVALENT OF HEAT

Heat and work are mutually convertible. When a definite amount of work is expended an equivalent amount of heat appears, and when a definite amount of heat is expended an equivalent amount of work appears.

If an amount of work W is done and during the performance of this work a quantity of heat equal to H is produced,

then
$$\frac{W}{H} = \text{a constant.}$$

If we call the value of this constant J , which is known as Joule's Equivalent, we have:

$$\frac{W}{H} = J.$$

Now introducing units,

$$\frac{W \text{ (ft.-lb.)}}{H \text{ (C.H.U.)}} = J = 1,400 \text{ ft.-lb. per C.H.U.}$$

and since $1 \text{ C.H.U.} = \frac{2}{5} \text{ B.Th.U.}$

$$\begin{aligned} \frac{W \text{ (ft.-lb.)}}{H \text{ (B.Th.U.)}} &= \frac{1,400}{\frac{2}{5}} \text{ ft.-lb. per B.Th.U.} \\ &= 778 \text{ ft.-lb. per B.Th.U.} \end{aligned}$$

Thus we may say that:

$1 \text{ Centigrade Heat Unit} = 1,400 \text{ ft.-lb.}$

and $1 \text{ British Thermal Unit} = 778 \text{ ft.-lb.}$

Determination of the Mechanical Equivalent of Heat by Callender's Apparatus

A brass drum A with a circular opening B is mounted on a spindle which rests on bearings fixed to a stand (Fig. 71). The drum can be rotated by means of the handle H and the number of revolutions is given by the revolution counter R . A silk ribbon is wrapped round the drum. One end of the ribbon is connected through a spring balance S to a horizontal cross-piece attached to the stand. The other end of the silk band supports a set of slotted weights W . As the drum is rotated the ribbon is kept taut and the spring balance indicates a reading. A special thermometer T , reading in tenths of a Centigrade degree, is inserted in the opening B .

To perform the experiment, a quantity of water of known weight is inserted in the drum, and the temperature of the water is noted. The drum is rotated a known number of times and the temperature of the water is again noted. The reading of the spring balance is also noted at intervals and the average reading is determined.

A typical set of results is shown below:

Diameter of drum	= 3 in.
Mean spring balance reading	= 0.26 lb.
Suspended weight	= 1.20 lb.
Weight of drum	= 0.55 lb.
Specific heat of brass	= 0.09
Weight of water	= 0.22 lb.
Number of revolutions	= 1,000
Initial temperature of water	= 16.3° C.
Final temperature of water	= 18.2° C.
Frictional force on drum	= 1.20 - 0.26 lb. = 0.94 lb.
Work done per revolution	= $0.94 \times \frac{3}{12} \times \pi$ ft.-lb.
Work done in 1,000 revolutions	= $1,000 \times 0.94 \times \frac{3}{12} \pi$ ft.-lb.
Water equivalent of drum	= 0.55×0.09 lb.
Heat gained by drum and water	= $(0.22 + 0.55 \times 0.09) \times$ 1.9 C.H.U.

$$\text{Hence: } J = \frac{1,000 \times 0.94 \times 0.25 \pi}{(0.22 + 0.09 \times 0.55) \times 1.9} \text{ ft.-lb. per C.H.U.}$$

$$= 1,442 \text{ ft.-lb. per C.H.U.}$$

Example. What amount of work is equivalent to the heat required to raise the temperature of 1,000 lb. of water from 60° F. to 90° F.?

$$J = 778 \text{ ft.-lb. per B.Th.U.}$$

$$\text{Heat required} = 1,000 \times 30 \text{ B.Th.U.}$$

$$= 30,000 \text{ B.Th.U.}$$

$$\text{Work equivalent} = 30,000 \times 778 \text{ ft.-lb.}$$

$$= 23,340,000 \text{ ft.-lb.}$$

Example. The weight of a flywheel is 1,200 lb. and the diameter of its shaft is 3 in. If the coefficient of friction between the shaft and its bearings is 0.05 and the shaft makes 300 revolutions per minute, calculate the heat produced in the bearings per hour. ($J = 1,400$ ft.-lb. per C.H.U.)

$$\text{From } \mu = \frac{F}{W},$$

where F = frictional force, W = load, and μ = the coefficient of friction,

$$\text{we have: } 0.05 = \frac{F}{1,200}$$

$$\therefore F = 1,200 \times 0.05$$

$$= 60 \text{ lb. wt.}$$

$$\text{Work done per revolution} = \pi \times \frac{3}{12} (\text{ft.}) \times 60 (\text{lb. wt.})$$

$$= 47.1 \text{ ft.-lb.}$$

$$\text{Work done per hour} = 47.1 \times 300 \times 60 \text{ ft.-lb.}$$

$$\therefore \text{Heat produced} = \frac{47.1 \times 300 \times 60}{1,400} \text{ C.H.U.}$$

$$= 605.6 \text{ C.H.U.}$$

EXERCISES

1. What amount of work is equivalent to the heat required to raise the temperature of 500 lb. of water from 0°C. to 100°C. ? ($J=1,400$ ft.-lb. per C.H.U.)
2. A vessel, of water equivalent 3 lb., contains 40 lb. of water at 60°F. The water is churned by a paddle wheel working at 4 h.p. Assuming no heat losses, find the temperature of the water after 10 minutes.
3. The perpendicular force between a shaft, diameter 2 in., and its bearings is 200 lb. wt. and the coefficient of friction is 0.1. If the shaft makes 300 revolutions per minute, calculate the heat produced per hour. ($J=1,400$ ft.-lb. per C.H.U.)

CHAPTER X

CONDUCTION, CONVECTION AND RADIATION

TRANSFER OF HEAT

Heat may be transferred from one point to another by conduction, convection and radiation.

When a poker is held in the fire, heat travels along it from the fire to the hand, that is from the hot end to the cold end, and there is a gradual fall in temperature along the poker.

If we consider the poker to consist of a line of particles A, B, C, D, E, etc., where A is the hot end, the heat passes along the particles in the direction of A to E. The particle A transfers some of its heat to the particle B, B transfers some of its heat to C and so on and the temperatures of the particles A, B, C, D, E, etc., are in descending order of magnitude. This mode of transfer of heat is known as conduction, which takes place mainly in solids.

When a beaker containing water is placed on a tripod and heated by means of a bunsen burner, the water just above the flame expands, becomes less dense and rises to the surface. Heat is carried by the particles of water in a stream (Fig. 72) and a cold water current descends from the surface of the water to the bottom of the beaker to keep up the circulation. This mode of transfer of heat is known as convection and takes place in liquids and gases.

If a person stands directly in the sun's rays and then in the shadow cast by a wall, the effect of radiant heat can be understood. Thus in Fig. 73a the point A is directly under the influence of the sun's rays, but in Fig. 73b the point A is shielded. From this we can see that radiant heat travels in straight lines as in the case of light. Moreover, the material through which radiant heat passes is not heated. In fact, radiant heat can pass through a vacuum as in the case of the space between the sun and the earth and the mode of transfer is known as radiation.

CONDUCTION OF HEAT

Substances which allow heat to pass through them very readily are known as good thermal conductors, whereas those substances which allow heat to pass through them with

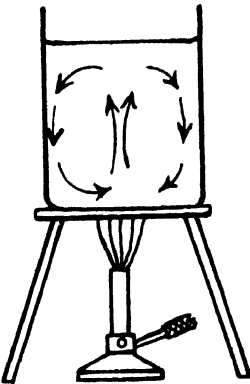


FIG. 72

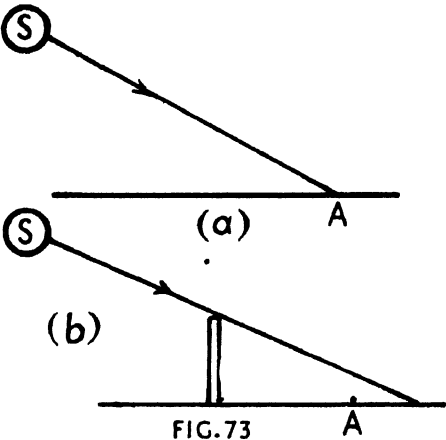


FIG. 73

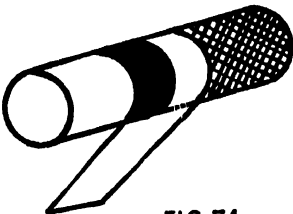


FIG. 74

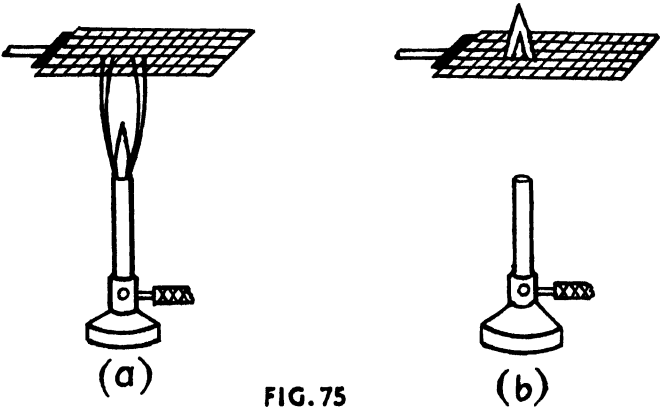


FIG. 75

difficulty are known as poor conductors or thermal insulators. Metals are good thermal conductors and, in general non-metals such as wood, paper, vulcanite, bakelite, etc., are poor thermal conductors.

Fig. 74 shows a compound bar, one part of which is made of wood and the other part of brass. A sheet of paper is wrapped round the dividing line and the bar is held over a bunsen flame so that the joint is in the flame. The paper over the wood is burned while that over the brass is unaffected. In the case of the brass which is a good thermal conductor the heat is conducted away from the paper rapidly, whereas in the case of the wood, a poor thermal conductor, the heat remains in the paper, raises it to its ignition temperature (see p. 226) and the paper burns.

The Wire Gauze Experiment

If a sheet of iron gauze is held about two inches above a bunsen burner and, with the gas turned on, a light is applied below the gauze, the flame extends to the gauze and no further (Fig. 75). If the light is applied above the gauze, the flame does not extend below. The iron gauze, being a good thermal conductor, conducts the heat away from the flame and the gas on the other side of the gauze does not reach its ignition temperature.

PRACTICAL APPLICATIONS

Both good and poor thermal conductors have their uses in industry. The wire gauze experiment described above has its main practical application in the miner's flame safety lamp.

FLAME SAFETY LAMP

The outer portions of the lamp (Fig. 76) may be divided into three sections, the bonnet A, the frame B and the fuel tank or base C. The frame is screwed into the base and is locked either by means of a lead rivet or a magnetic lock. The bonnet is screwed into the frame ring L and, when the lamp is assembled, is held in a locked position by a locking spindle. The frame consists of a base and a top ring which are rigidly connected by five fixed standards D and the locking spindle is held in position by the frame.

The internal assembly of the lamp is as follows. An asbestos ring E is placed on the frame base and the lamp glass F is mounted on it. This glass is prevented from any lateral movement by a circular metal flange which forms part of the frame

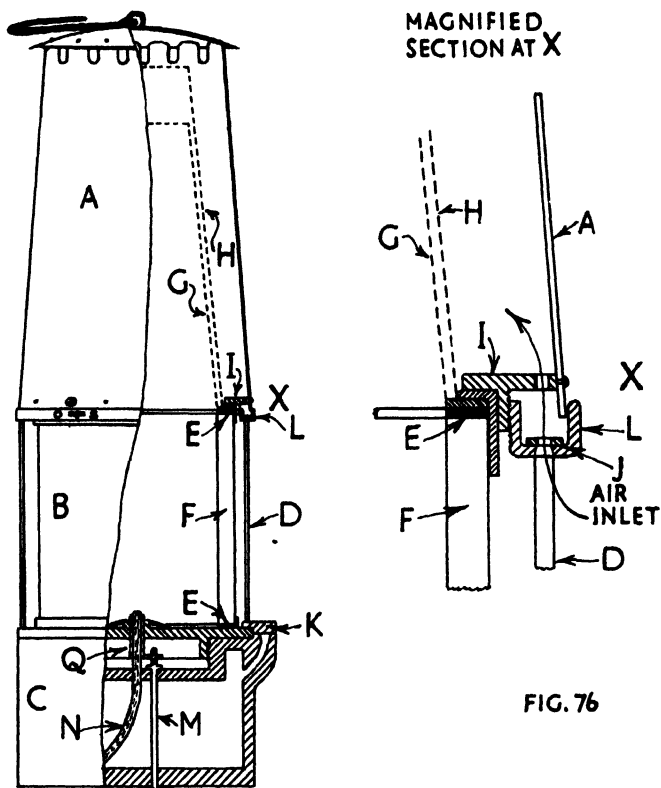


FIG. 76

**FLAME SAFETY LAMP (RELIGHTER TYPE)
RELIGHTER SYSTEM OMITTED**

BONNET—A
 FRAME—B
 FUEL TANK—C
 STANDARD—D
 ASBESTOS RING—E
 GLASS—F
 INNER GAUZE—G
 OUTER GAUZE—H

BRASS RING—I
 BOTTOM FEED—J
 CONTROL RING
 LOCK—K
 FRAME RING—L
 WICK TUBE—M
 CONTROLLER
 WICK—N
 WICK TUBE—Q

base. Another asbestos ring is placed on the top of the glass and the inner gauze G which is generally of 20 or 28 mesh is set in position on it. The outer gauze H of similar mesh is then fitted over the inner one. This outer gauze is provided with a flange

which extends round the glass and prevents lateral displacement between gauzes, asbestos ring and glass.

The internal brass ring I which is riveted to the bonnet is also provided with a flange which presses down on the gauzes when the bonnet is screwed into the frame ring. The asbestos rings are provided so as to obtain airtight and flame-proof joints between the glass and the metallic surfaces of the inner gauze and the frame base.

The air supply enters the lamp through a series of perforations in the frame ring. This supply, however, may be cut off by means of a control ring J which has similar perforations. The movement of the ring is such that in one position the two series of perforations coincide and in another position there is no coincidence. When the air supply passes through the frame ring the lamp is said to be in "bottom feed." If this supply is cut off the air enters the perforations near the top of the bonnet and the lamp is in "top feed." In this case the lamp may be usefully employed in the detection of methane near the roof. The control ring is moved by a catch fitted through the frame ring, the two positions "open" and "shut" being marked O and S.

THE LAGGING OF PIPES

Felt, asbestos, etc., being poor conductors of heat, are used for wrapping round steam pipes to keep them hot. In this manner, very little heat is allowed to pass from the pipes to the surrounding air. The temperature of the surface of the non-conducting material in contact with the pipes is practically the same as that of steam, whereas the outer surface of the material is not much above air temperature.

CONVECTION OF HEAT

Fig. 77a shows an apparatus which is used for illustrating convection currents in water. A flask A is provided with a rubber stopper which is fitted with the glass tubes BC and DE. These tubes have their exits in a glass vessel F. The flask is filled with coloured water and the vessel F along with the tubes BC and DE contain pure water. When the water in the flask is heated, a stream of coloured water rises up the tube DE and enters the vessel F, colouring the water at the top. It is evident that in order to keep the flask A filled, cold water must descend the tube CB which reaches to the bottom of the flask.

A practical application of convection currents in liquids is the hot-water system of a building (Fig. 77b) or the hot-water

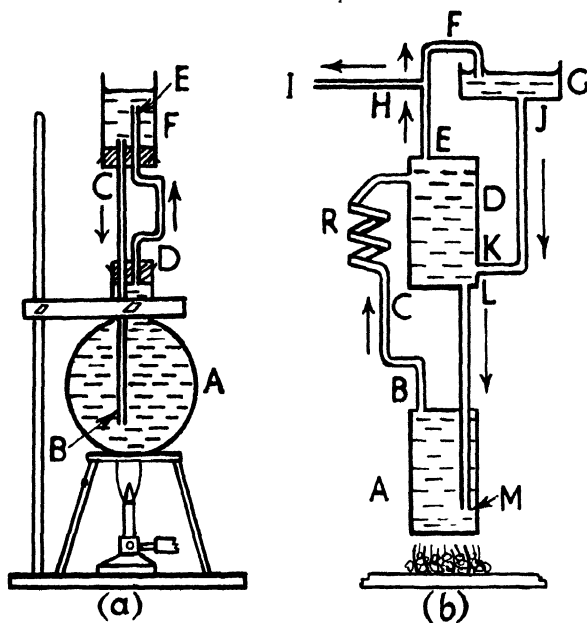


FIG. 77

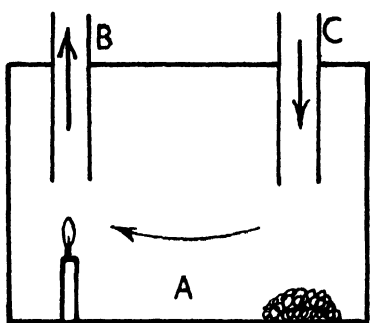


FIG. 78

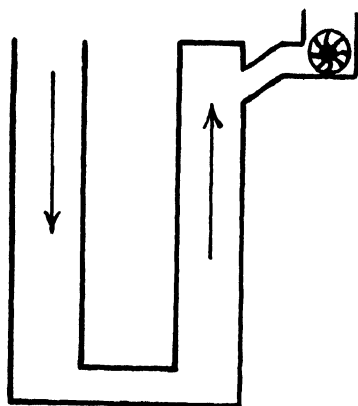


FIG. 79

supply for pit-head baths. Hot water from the boiler A passes up the pipe BC, through the radiator R to the top of the cistern D. Another pipe EF leads from the top of the cistern to a tank G which contains cold water. A branch pipe HI leads to the bath, sink, etc. To keep up the circulation, cold water descends the pipe JK and enters the bottom of the cistern. Cold water also descends the pipe LM which leads to the bottom of the boiler.

Convection Currents in Air

A box A, possessing a glass front, is fitted with two tubes B and C which serve as chimneys (Fig. 78). If smouldering paper is placed directly under the tube C and a lighted candle is placed underneath the tube B, the air above the candle is heated, becomes less dense and rises up the tube, carrying with it particles of charred paper. To keep up the circulation, a cold air current descends the tube C.

The Ventilation of a Coal Mine

The above principle used to be generally employed in the ventilation of a mine. A fire was kept burning at the bottom of the upcast shaft. The heated air ascended this shaft and a cold air current descended the downcast shaft to keep up the circulation. In modern mines, however, forced convection is used. A centrifugal fan is placed near the top of the upcast shaft (Fig. 79) and the air in this shaft is drawn by the fan into the atmosphere. An air current descends the downcast shaft to keep up the circulation.

EXERCISES

1. Sketch, and describe, either (a) a flame safety lamp, or (b) an electric safety lamp. Which type of lamp do you prefer and why?
(Min. Sc.; U.L.C.I.)
2. Describe experiments to illustrate the principle of the flame safety lamp.
(Min. Sc.; U.L.C.I.)
3. Explain what you understand by conduction, convection and radiation of heat. Give an example of each from mining practice.
(Min. Sc.; U.L.C.I.)
4. What is meant by conduction of heat? Describe an experiment which illustrates the principle of the flame safety lamp. Under what circumstances is a cap formed and what use can be made of it?
(Min. Sc.; U.E.I.)
5. Describe one experiment in each case to show convection currents (a) in a liquid, (b) in air. Give examples of convection in mining.
(Min. Sc.; U.L.C.I.)

6. Explain the difference between conduction and convection of heat. Describe an example of the utilisation of conduction of heat in mining practice. (Min. Sc.; U.L.C.I.)

7. Explain why an ignition of gas inside a flame safety lamp does not readily ignite gas outside the lamp. What is meant by "flame-proof switch-gear"? How is such apparatus made flame-proof?

(Min. Sc.; U.L.C.I.)

CHAPTER XI

THE ELECTRIC CIRCUIT AND REPRESENTATION OF ELECTRICAL PARTS

INTRODUCTION

Every mining student is familiar with some of the electrical devices which are to be found both on the surface and underground, such as accumulators, terminals, bells, switches, etc. They have also some idea of the use of the ammeter and voltmeter, having seen these instruments in mining laboratories, power stations, etc. But before dealing in detail with the principles underlying electrical appliances it is necessary to explain a few terms which are in common use in electrical practice and also to show how electrical appliances are represented in diagrams.

CONDUCTORS AND INSULATORS

All substances may be classified, as far as the passage of an electric current is concerned, into (a) conductors and (b) insulators. Substances which allow electricity to pass through them with little resistance to the current are known as conductors, whereas substances which allow electricity to pass through them with difficulty or with a great resistance to the current are known as insulators. Substances which are good thermal conductors are also good electrical conductors and vice versa. Thus all metals, including the liquid mercury, are good conductors of electricity. Ebonite, wood, rubber, bakelite, etc., are electrical insulators.

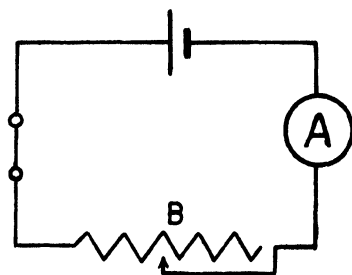
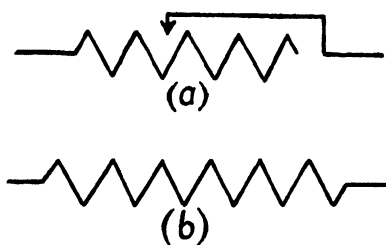
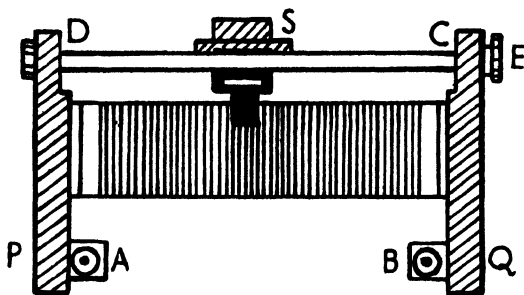
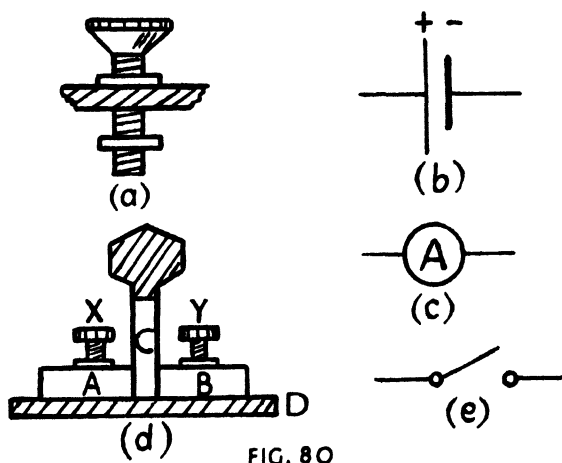
Screw Terminals

A terminal (Fig. 80a) serves as an inlet or an outlet for an electric current.

REPRESENTATION OF VARIOUS ELECTRICAL PARTS BY DIAGRAMS

The Accumulator

The accumulator possesses two terminals. An electric current leaves the positive terminal and after passing through the various resistances, etc., re-enters the cell at the negative terminal. An accumulator is shown in diagrams as in Fig. 80b.



The Ammeter

The ammeter is an instrument designed for measuring the strength of an electric current. The instrument possesses a scale marked 0—1 amperes,* 0—10 amperes, etc., according to the strength of the current it is intended to measure. Fig. 80c shows how an ammeter is represented diagrammatically.

The Plug Key

The plug key (Fig. 80d) supplies a ready means of completing or breaking an electric circuit. Two slabs of brass A and B, fitted with screw terminals X and Y, are mounted on an ebonite base D. The brass plug C which is provided with an ebonite handle connects the plates A and B and an electric current can flow from one terminal to the other. Fig. 80e shows how a plug key is represented diagrammatically.

Fixed and Variable Resistances

A long piece of wire offers more resistance to an electric current than a short piece of the same material and diameter. Thus with a variable resistance which consists of a long coil of wire, various lengths of wire may be included in an electric circuit. The resistance of the circuit is thereby varied with a consequent variation in the current strength. Fig. 81 shows a variable resistance. Insulated wire (i.e. wire covered with some insulating material such as cotton thread, shellac, etc.) is wound round a porcelain tube and the ends of the wire are fixed to the terminals A and B. The steel rod CD, along which the slider S moves, is insulated from the supports P and Q and carries a terminal E at one end. If the current enters at A it traverses the coil as far as the slider S and then passes along the rod to the terminal E.

When the current enters at A and leaves at B, it traverses the whole length of the coil. The resistance is now constant and the appliance becomes a fixed resistance. Figs. 82a and 82b show how variable and fixed resistances are represented in circuit diagrams.

The Complete Circuit

Fig. 83 shows a complete electric circuit. The current leaves the accumulator, passes through the plug key, through the variable resistance as far as B and then through the ammeter A, to the negative terminal of the accumulator.

* The ampere is the unit of current strength.

By including more of the variable resistance in the circuit, i.e. by moving the slider to the right, the total resistance round the circuit is increased and the current thereby decreased. This is shown by the ammeter A. Vice versa, by moving the slider to the left, the resistance is decreased and the current increased.

CHAPTER XII

MAGNETISM AND ELECTROMAGNETISM

MAGNETISM

Magnetism is that property of a substance which is utilised in the mariner's compass or the miner's dial. Both these instruments depend on the principle that a compass needle which possesses a north pole at one end and a south pole at the other sets itself along a definite direction which is known as the magnetic meridian. The north pole of the needle points to the North Magnetic Pole of the earth, and the south pole of the needle to the South Magnetic Pole. The geographical meridian at a point on the earth's surface is the true North and South line through this point and the direction of the magnetic meridian at this point makes an angle of 17° West with the geographical meridian (Fig. 84). The angle between the geographical and magnetic meridians is known as the angle of declination.

By means of the miner's dial, which in effect is a freely suspended compass needle, the direction of the magnetic meridian underground and consequently the true North and South line can be determined.

Attraction and Repulsion

A bar magnet also possesses a north pole at one*end and a south pole at the other and when freely suspended shows the same directional property as the compass needle. If a bar magnet A is suspended in a paper stirrup and the north pole of another bar magnet B is brought near the north pole of the suspended magnet, this latter pole is repelled. If the south pole of the magnet B is brought near the north pole of the magnet A, this latter pole is attracted. Thus a north pole repels a north pole free to move and a south pole attracts a north pole. Similarly a south pole attracts a north pole and repels a south pole. In a more general way we may say that like poles repel each other and unlike poles attract each other.

If a thin rod of unmagnetised steel is suspended in the stirrup and either pole of a bar magnet is brought near each end of the rod in turn, attraction takes place in each case.

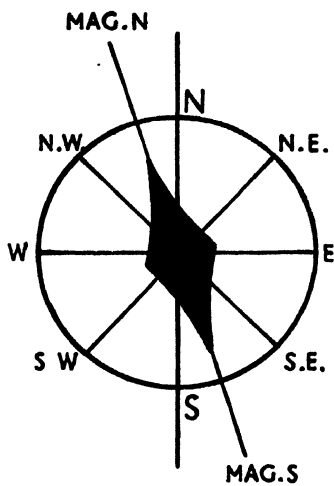


FIG. 84

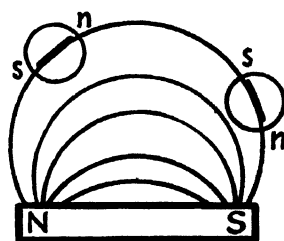
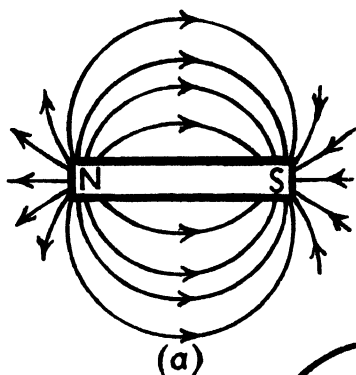
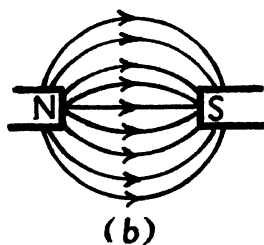


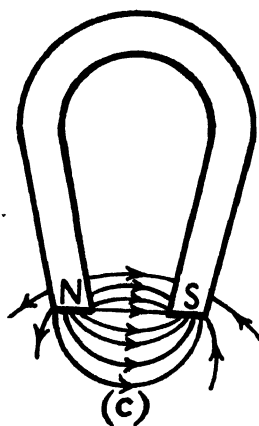
FIG. 85



(a)



(b)



(c)

FIG. 86

MAGNETIC FIELDS

If one end of a bar magnet is immersed in a dish containing iron filings, when the magnet is withdrawn a cluster of filings clings to the magnet. This attractive force, however, is not confined to the surface of the magnet. At points removed from the surface, the attractive force is operating. A compass needle, placed a few inches from a pole of a bar magnet, sets itself in a definite direction. *The space around the magnet, at any point of which the magnet exerts a force, is known as the sphere of influence or the field of the magnet.*

If a bar magnet is placed on a sheet of paper and a small compass needle is placed near its north pole, the position *n* of the end of the compass needle remote from this pole can be marked. If the compass needle is now moved until its south pole is opposite the mark *n* and the process is repeated, a line of dots is obtained on the paper. It will be found that the line stretches from the north pole of the magnet to the south pole. This line is known as a line of force. Other lines of force can be plotted until the magnetic field is completed (Fig. 85).

A line of force of a magnet is the path traced out by a single north pole, free to move, and stretches from the north pole of the magnet to the south pole. Fig. 86a shows the lines of force due to a single bar magnet. The lines describe circuitous paths from the north to the south poles. Fig. 86b shows the lines of force due to two bar magnets in line, with the north and south poles opposite each other, and Fig 86c shows the lines of force due to a horse-shoe magnet.

MAGNETIC EFFECTS OF AN ELECTRIC CURRENT

Fig. 87 shows a long coil R consisting of about 100 turns of cotton-covered copper wire of S.W.G. 20. The electric circuit is arranged with an accumulator B in series with the coil R, a variable resistance VR and a plug key K. A soft-iron rod is placed in the coil and a small dish containing iron filings is supported underneath the exposed end of the rod. When the key is inserted and the variable resistance is adjusted so as to obtain a suitable current, iron filings collect in a cluster on the end of the rod. When the circuit is broken by withdrawing the plug key the filings fall off the rod.

The experiment evidently shows that a bar of soft iron can be magnetised by means of a coil of wire conveying a current. It also shows that the soft iron only remains magnetised so long as the electric current flows. The magnetism acquired is known as temporary magnetism.

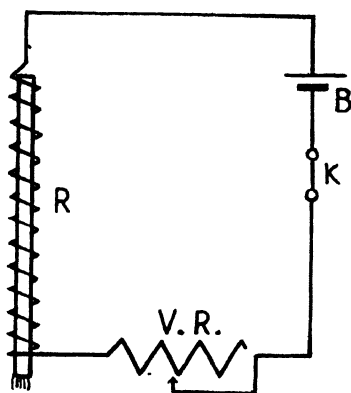


FIG. 87

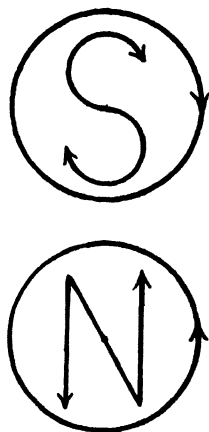


FIG. 88

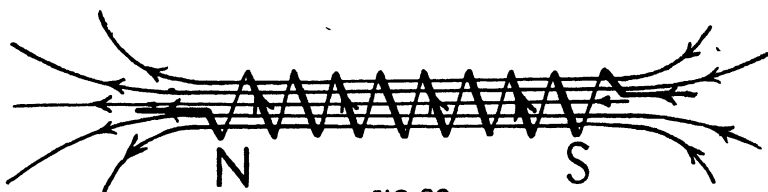


FIG. 89

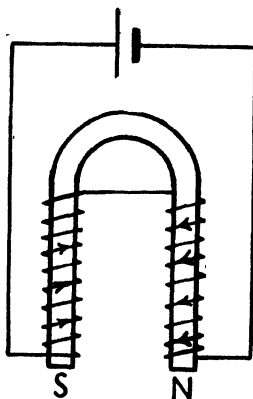


FIG. 90

If the experiment is repeated with a steel knitting needle and the current is passed for a considerable time, a cluster of filings again collects on the exposed end of the needle. The filings also remain on the rod when the current is discontinued.

In this case the magnetism acquired is known as permanent magnetism. Thus temporary magnetism only exists as long as the magnetising current continues to flow, but permanent magnetism remains after the magnetising current is discontinued.

Polarity of a Long Coil of Wire conveying an Electric Current

An accumulator, a long coil of wire, a variable resistance and a plug key are arranged as in Fig. 87, but the soft-iron rod is dispensed with. If the wiring of the circuit is examined, the direction of the current, clockwise or counter-clockwise when viewed from one end, may be ascertained. If the plug key is inserted and the current is increased a compass needle, placed near this end, is deflected according to the following rule. If the current flows in a clockwise direction, the north pole of the needle is attracted, whereas if the current is counter-clockwise, the south pole is attracted. Thus on viewing one end of the coil directly, if the current is clockwise, this end is a south pole, but if the current is counter-clockwise the end of the coil is a north pole (Fig. 88).

A coil conveying a current has therefore a magnetic field associated with it. The lines of force leave the north pole and, after circuitous paths, re-enter the south pole (Fig. 89).

The Electromagnet

Fig. 90 shows an electromagnet, shaped like a horse-shoe. The soft iron is wound with insulated wire in such a manner that, when the current flows, one end of the coil becomes a north pole and the other end a south pole. Lines of force leave the north pole and enter the south pole and these lines constitute the field of the magnet. Since the core is made of soft iron, the magnetism acquired is temporary magnetism.

Magnetic Materials

If thin rods of various materials such as iron, steel, nickel, aluminium, tin, glass, etc., are placed in the coil of wire shown in Fig. 87, it will be found that iron, steel and nickel can be magnetised, whereas tin, aluminium, glass, etc., are unaffected.

Substances such as iron, steel and nickel which can be magnetised are known as magnetic materials and substances which cannot be magnetised are known as non-magnetic materials.

The Electric Bell

The wiring system of an electric bell is shown in Fig 91. The current enters at the terminal A, passes through the coils of the electromagnet E to the steel spring D, which is attached to a bracket C. The current then passes along the soft-iron rod F, through the leaf G which consists of a thin strip of steel and through the contact screw H to the terminal B. The current magnetises the soft-iron core of the electromagnet, the soft-iron rod F is attracted and the hammer I, attached to the rod F, strikes the bell J. In this operation the circuit is broken at the contact H, the soft-iron core loses its magnetism and the spring D restores the rod F and the leaf G into contact with the screw H. The operation is then repeated and continued as long as the current continues to flow.

Electric equipment, including special types of electric bells which are free from dangerous sparking at make and break, are used extensively in mines where signals have to be given in haulage and other operations, and a knowledge of the construction, use and repair of this equipment is essential in modern mining practice.

The Telephone

The principle of the electromagnet is also utilised in the telephone, which consists of a microphone A and a receiver B (Fig. 92). The main features of the microphone are an ebonite cylinder C, closed by a thin carbon diaphragm D and a carbon plate E which is fitted with a terminal X. Another terminal Y is attached to the diaphragm D and the cylinder contains loosely fitting carbon granules. Leads connect the terminals X and Y through a battery of cells, to the coils of the permanent magnet M of the receiver and the winding of the coils is such as to increase its magnetisation when the current flows.

A thin diaphragm of soft iron F is fitted in the ebonite casing near the poles of the magnet. The sound waves from the speaker set the diaphragm D in vibration and this alters the spacing of the carbon granules, producing an alteration in the resistance and a consequent alteration in the current through it. The variation of the current produces a variation in the strength of the permanent magnet M and the soft-iron diaphragm F is

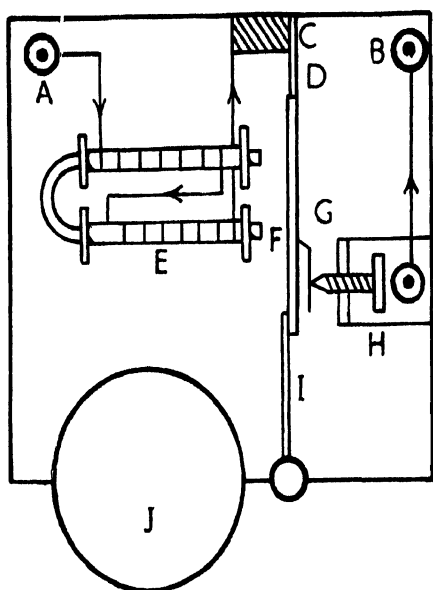
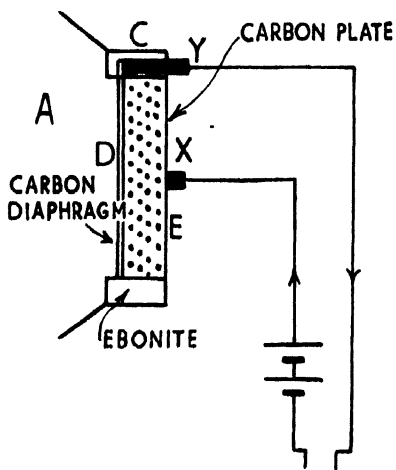


FIG. 91

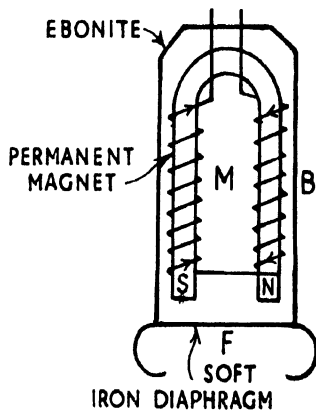


FIG. 92

set in vibration. The ear placed near the receiver receives the sound due to these vibrations.

Telephones are installed in mines for conveying messages from one point to another.

MOTION OF A CONDUCTOR, CONVEYING A CURRENT, IN A MAGNETIC FIELD

Fig. 93 shows a strong electromagnet E, arranged so that its poles project over the edge of the bench. A soft-iron rod A is supported horizontally in a stand (not shown in the diagram) and a copper rod C, fitted with a hook, is suspended from one end. The rod C is adjusted so that it rests in and at right angles to the magnetic field between the pole-pieces N and S. One end of a piece of flex wire F is soldered to the lower end of the rod C and the other end of the flex is connected to the positive terminal of an accumulator B. The negative terminal of the accumulator is connected through a variable resistance R to a screw terminal D, attached to the rod A. With this arrangement the current passes up the rod C.

Starting with the whole of the variable resistance in the circuit, if the resistance is quickly decreased with a consequent increase in the current, the lower end of the rod C moves into the space between the coils of the electromagnet. When the terminals of the accumulator are interchanged so that the current flows down the rod C, and the current is again increased, the lower end of the rod moves in the opposite direction.

If a plug key is placed in the circuit, by inserting the plug and starting the current, the rod C is again set in motion. Thus if a conductor is at right angles to a magnetic field and a current is started or increased, the conductor moves across the magnetic field so as to cut the lines of force.

It will be seen from the diagram (Fig. 94) that the directions of the field, the current and the motion are mutually at right angles. We are thus led to *Fleming's Left-hand Rule* which can be stated as follows: *If the thumb, the first finger and the second finger of the left hand are held mutually at right angles to one another and if the first and second fingers point in the directions of the field and the current respectively, then the thumb points in the direction of the motion.*

The Moving-coil Galvanometer

A practical example of Fleming's Left-hand Rule is the action of a moving-coil galvanometer (Fig. 95a). M is a permanent magnet with shaped pole-pieces N and S. A cylinder of soft

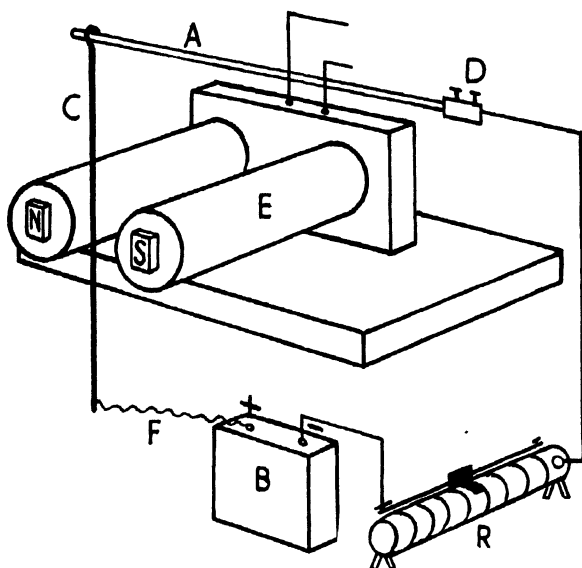


FIG. 93

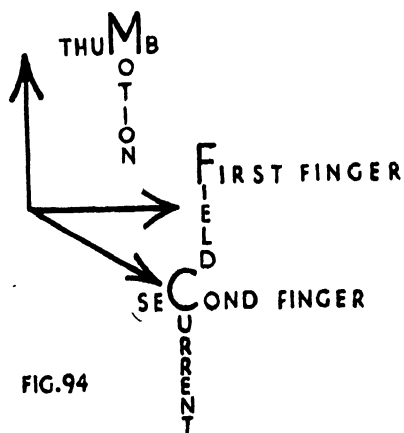


FIG. 94

iron (shown in Fig. 95b) is mounted centrally between the pole-pieces and the combination of the soft-iron cylinder and the curved pole-pieces produces a radial field.

PQ represents one side of a rectangular coil mounted on a spiral spring R. The opposite side is mounted on a similar spring (not shown in the diagram). The coil consists of several turns of thin insulated wire and is free to move in the space between the poles and the soft-iron cylinder. When the current enters at

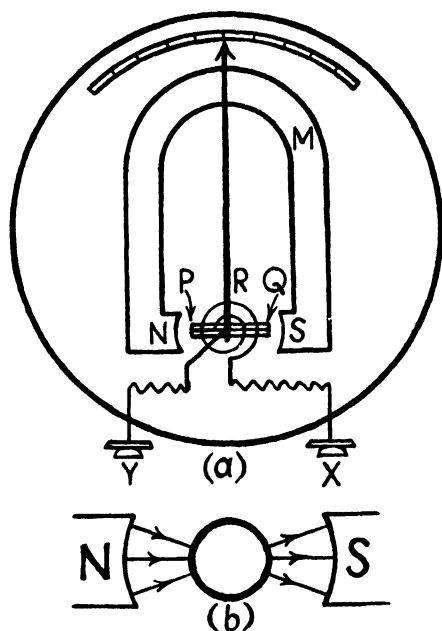


FIG. 95

the terminal X, it passes through the spring R, through the coil PQ and out at the terminal Y.

If the current goes down the right-hand side of the coil at Q and up the left-hand side at P, by the Left-hand Rule the coil, along with the pointer attached to it, rotates in a clockwise direction. If the current enters at Y and leaves at X, the coil rotates in a counter-clockwise direction.

The spring R, by winding or unwinding as the deflection increases, acts as a control and the coil takes up a position of equilibrium.

It will be seen that the instrument both detects a current and also gives its direction.

PRODUCTION OF A CURRENT BY THE MOTION OF A CONDUCTOR ACROSS A MAGNETIC FIELD

In Fig. 96 ABCD is a coil, consisting of about 20 turns of ordinary connecting wire. A piece of double flex wire F connects the ends of the coil to the terminals of a galvanometer G. A strong horse-shoe magnet M is placed on the table and the coil ABCD is placed near it, with the sides AB and CD vertical.

If the windings of the coil and the flex are examined the direction of the current in the coil which produces a galvanometer deflection to the right or to the left can be deduced. If the coil is now moved into the space between the poles N and S of the magnet, it will be noticed that the deflection is in such a direction that a current flows from A to B. When the coil is moved away from the magnet it will be found that a current flows from B to A.

The experiment shows that if a conductor which forms part of a complete circuit cuts across the lines of force of a magnetic field, (a) a current, known as an induced current, is produced in the conductor, (b) the current only lasts as long as the motion is taking place and (c) the direction of the current is given by the following rule (*Fleming's Right-hand Rule*): *If the first and second fingers and the thumb of the right hand are held mutually at right angles to one another and if the first finger and thumb point in the directions of the magnetic field and the motion of the conductor respectively, then the second finger points in the direction of the induced current* (Fig. 97).

THE DYNAMO

The dynamo is based on Fleming's Right-hand Rule for induced currents. Fig. 98 shows a rectangular coil ABCD rotating in the space between the poles N and S of an electromagnet. Copper slip-rings E and F are mounted on a spindle the axis of which is coincident with the line PQ. The rings E and F are insulated from the spindle and are connected to the sides AB and CD of the coil respectively. As the spindle rotates so does the coil ABCD.

Suppose the coil is horizontal (Fig. 98). As AB moves upwards and CD moves downwards, a current is induced in the directions A to B and C to D. The current leaves the coil by the carbon brush L which rests on the ring F, traverses the external circuit and re-enters by the carbon brush K which rests on the ring

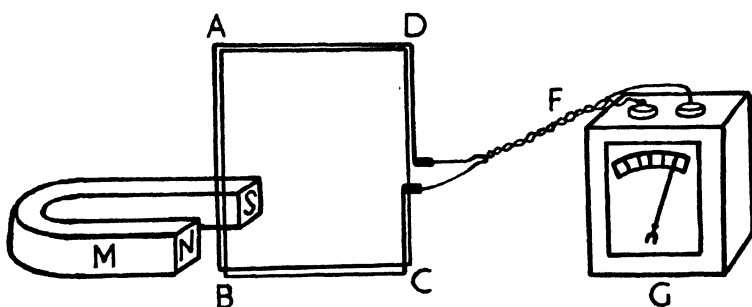


FIG. 96

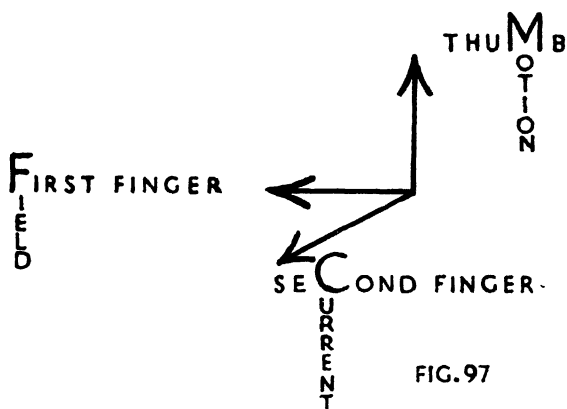


FIG. 97

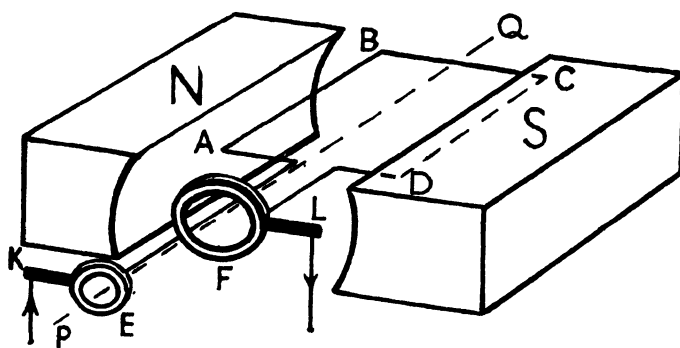


FIG. 98

E. When the coil is vertical the sides AB and CD move in a direction parallel to the field and, since no lines of force are cut, no current flows. But when CD replaces AB, the current enters the ring F by the brush L, flows from D to C in CD and from B to A in AB. Thus the current changes its direction in the coil and in the external circuit and is known as an alternating current.

The Direct-current Dynamo

As we have seen, the arrangement described above produces an alternating current both in the coil itself and in the external circuit. To produce a direct current, that is, a current flowing in the same direction in the external circuit all the time, a split-ring commutator is used. The commutator consists of two semi-rings X and Y which are made of copper. They are mounted on the spindle as before and are also insulated from it. The sides AB and CD of the coil are connected to Y and X respectively. As AB moves upwards and CD downwards (Fig. 99a) a current flows from A to B in AB and from C to D in CD. The current leaves the coil by the brush L which rests on X and, after passing round the external circuit, re-enters at the brush K which rests on Y. When the plane of the coil is vertical (Fig. 99b) no current flows and the brushes are in contact with the spaces between X and Y. When AB and CD interchange positions (Fig. 99c), the current in AB runs from B to A and the current in the external circuit flows in the same direction as before. But when the coil is again vertical no current flows and the brushes are again in contact with the spaces between X and Y. Thus it can be seen that the current changes direction in the coil every time the brushes are in contact with the spaces, but the current in the external circuit is maintained in the same direction for all positions of the coil.

THE ELECTRIC MOTOR

An A.C. dynamo may be converted into an A.C. motor by passing an electric current into it from another A.C. dynamo. Thus if the current enters by the brush K (Fig. 98), by Fleming's Left-hand Rule the side AB of the coil moves downwards and the side CD upwards.

Similarly a D.C. dynamo may be converted into a D.C. motor by passing an electric current into the coil ABCD at the brush K (Fig. 99a), and again the side AB moves downwards and the side CD upwards.

The Armature

In practice, both in motors and dynamos, the effect is multiplied by having a number of coils mounted on a frame known as the armature, which is mounted on the rotating spindle.

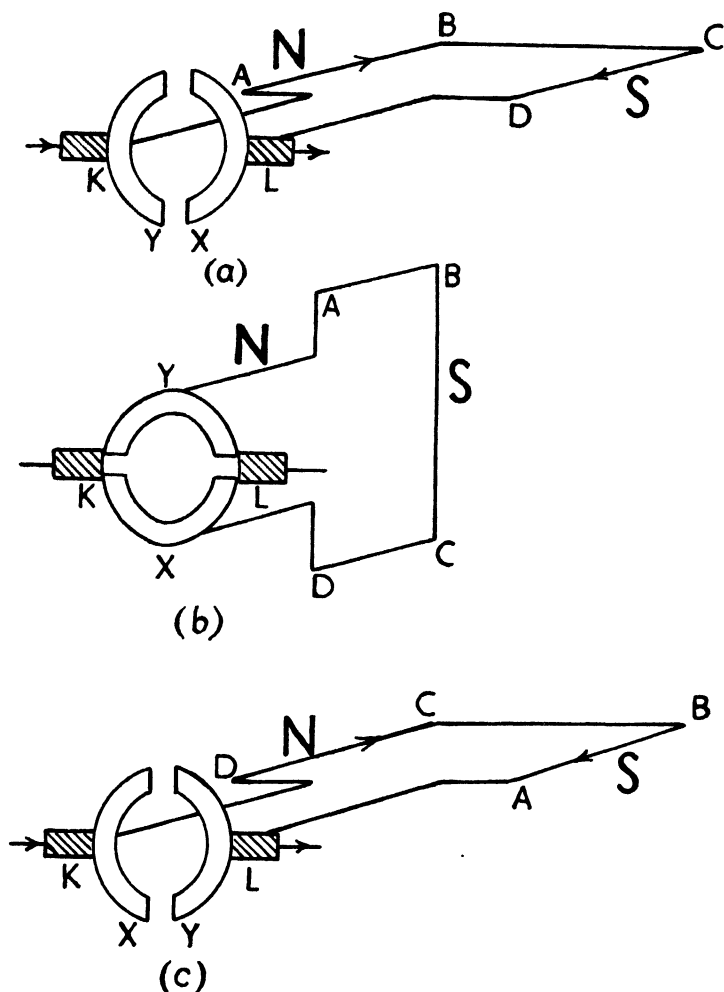


FIG. 99

DYNAMOS AND MOTORS IN MINING

In modern mines A.C. supply from the local authority is supplied to the colliery power house, from whence it is transmitted by cables to the underground roadways, where it is

transformed down (see p. 134) for various requirements. In addition an A.C. generator giving the same voltage may be installed in the power house on the surface, and this supply is transmitted underground by cables, where it is employed when breakdown of the main supply occurs or at periods of light load.

LENZ'S LAW

Lenz's law for induced currents states that the direction of the induced current in a circuit is such as to oppose the motion which produces it.

This law may be verified by means of the apparatus shown in Fig 100. The windings of the coil A and circuit are examined so as to ascertain whether the galvanometer deflection is to the right or left for a clockwise current in the coil when viewed from the right-hand side. If the north pole of the bar magnet is inserted in the coil and the deflection of the galvanometer, right or left, is noted, the direction of the current in the coil, clockwise or counter-clockwise, may be deduced. When the pole of the magnet is withdrawn, it will be found that the current flows in the opposite direction. A set of results is shown below.

Motion of Pole	Deflection of Galvanometer	Direction of Current in Coil	Polarity of face of Coil
North pole approaches	Right	Counter-clockwise	North
North pole recedes	Left	Clockwise	South
South pole approaches	Left	Clockwise	South
South pole recedes	Right	Counter-clockwise	North

It will be seen from the above table that the polarity of the face of the coil is such as to oppose the motion of the magnet.

MUTUAL INDUCTION

We have already seen how an induced current is produced in a coil of wire by inserting a pole of a bar magnet inside it. We also saw that the induced current only lasts as long as the magnet is in motion, that is, during the time the number of lines of force through the coil is changing.

If the bar magnet is kept stationary and the coil is moved from the position A to the position B (Fig. 101) there is an increase in the number of lines of force through it and this also produces an induced current.

We are now in a position to understand how the starting or

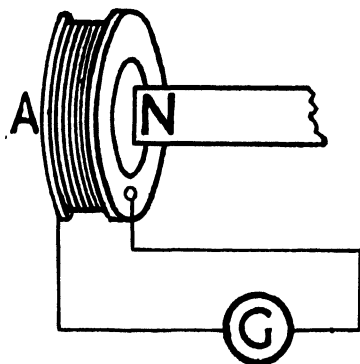


FIG. 100

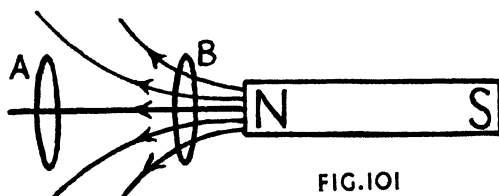


FIG. 101

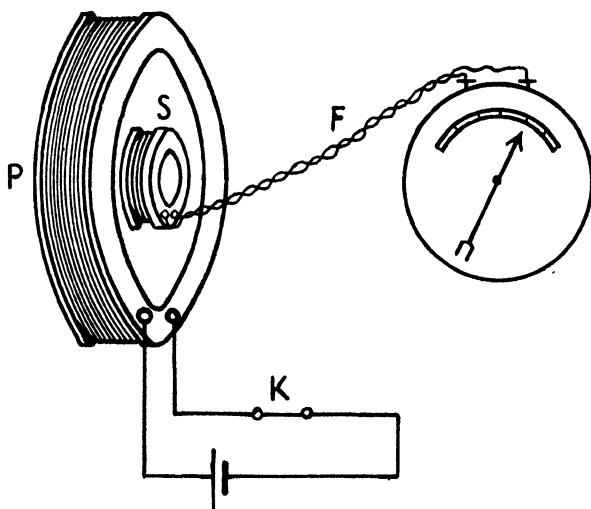


FIG. 102

the breaking of a current in a circuit produces an induced current in another circuit placed near to it.

A large coil P, consisting of several turns of ordinary connecting wire is arranged in series with a plug key K and an accumulator (Fig. 102). The terminals of a smaller coil S, consisting of several turns of the same kind of wire, are connected to the terminals of a galvanometer by means of a piece of double flex wire F. The diameter of the smaller coil is such that it can be inserted in the larger coil.

If the key K of the circuit is initially open and the key is then closed there is a deflection of the galvanometer needle which only lasts for an instant. When the current in the coil P is broken by withdrawing the plug, a momentary deflection of the galvanometer needle is again obtained but in the opposite direction.

The coils P and S are known as the primary and secondary coils respectively. There are no lines of force through the primary coil before it is closed, but when the current flows, lines of force are linked through it. Thus the starting of the current produces an increase in the number of lines of force through the secondary coil. This gives rise to an induced E.M.F. (see p. 156) in the secondary coil, which produces an induced current through this coil.

When the primary circuit is broken, there is a decrease in the number of lines of force through it and a corresponding decrease in the number of lines of force linked through the secondary coil. This gives rise to an induced E.M.F. in the secondary coil and an induced current flows in the opposite direction.

THE TRANSFORMER

The transformer is an application of mutual induction. Two coils of wire, the primary P and the secondary S, are wound on the same core of soft iron (Fig. 103). When an alternating current passes through the primary coil, first in one direction and then in the other, the magnetic field in the primary coil suffers a series of reversals. This produces reversals of the magnetic flux through the secondary coil with a consequent induced alternating current. When the primary contains only a few turns and the secondary a large number of turns, a small potential difference (see p. 141) applied to the ends of the primary coil produces a large potential difference between the ends of the secondary coil. This is known as a step-up transformer (Fig. 103a).

Fig. 103b shows a step-down transformer, in which there is a

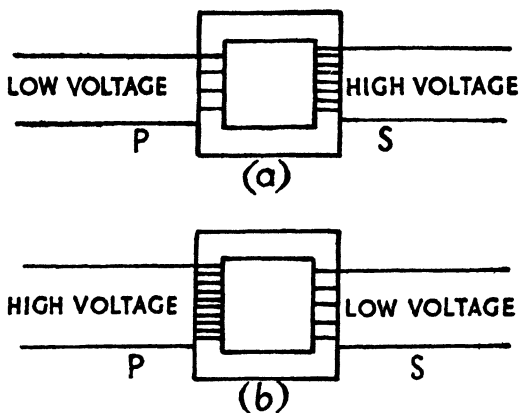


FIG. 103

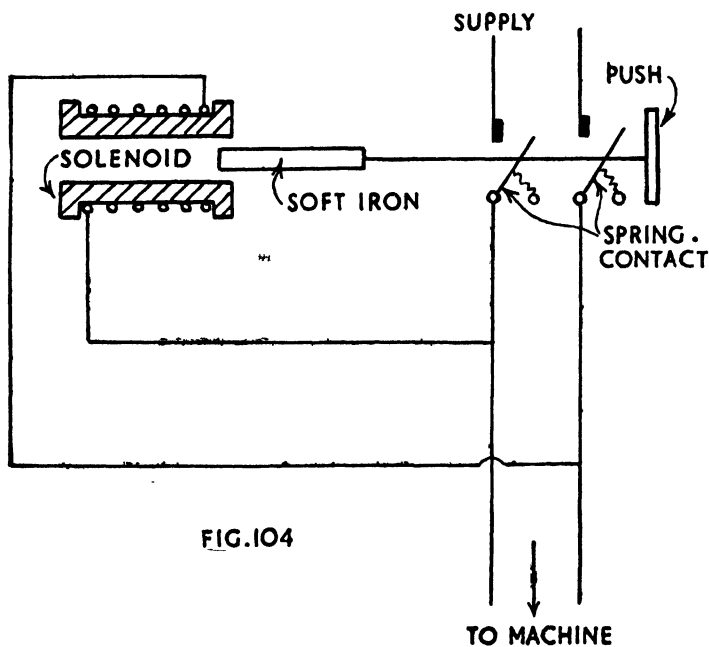


FIG. 104

large number of turns in the primary coil and a small number in the secondary coil. In this case a large potential difference applied to the terminals of the primary coil produces a small potential difference between the ends of the secondary coil.

THE USE OF TRANSFORMERS IN MINES

Transformers are used extensively in mining practice both on the surface and underground. They enable the supply voltage to be altered to suit the varying requirements of the electrical equipment used. For example, the supply voltage may be 2,200 volts A.C. and the following equipment may have to be supplied:

- (1) A pump motor at 220 volts A.C.
- (2) An electric coal-drilling machine at 110 volts A.C.
- (3) A coal-cutter at 440 volts A.C.
- (4) An underground lighting system at 110 volts A.C.
- (5) An electrically driven haulage engine at 440 volts A.C.

In each of the above-mentioned cases, the supply voltage must be stepped down to meet the requirements of the motor involved and thus suitable transformers will have to be installed.

FURTHER PRACTICAL APPLICATIONS OF ELECTROMAGNETISM

The No Volts Release

In order to prevent accidents due to the sudden starting-up of a machine in the event of a failure in the electric supply, certain types of switch-gear incorporate a device known as the no volts release which operates if the power is cut off. This renders the circuit between the switch-box and the machine dead even on recommencement of the supply and the circuit remains dead until the switch in the box is inserted again.

The remote control type of electrically driven coal-cutter is protected in this manner and the student will readily appreciate the danger of sudden starting-up of the cutter chains and picks if such protection in the switch-gear is not provided. The magnetic property of a current-carrying solenoid is the principle on which the no volts release is based and the arrangement is shown in Fig 104.

When the push is moved to the left, the contacts in the switch are closed and the power is supplied to the machine. The solenoid becomes a magnet and the soft-iron core is attracted. This keeps the contacts in the closed position and the springs are in considerable tension.

On failure of the supply the magnetic effect of the solenoid is lost and the springs open the contacts, which can only be closed again by manual operation.

The Overload Trip

A common feature of machinery driven by electric power is the danger of overloading for excessive periods. In such circumstances the heat produced in conductors carrying heavy load currents is much greater than normal. This may be detrimental to the insulation and may finally cause failure of the conductors.

To prevent such occurrences, the machines may be protected by incorporating in the switch-gear an overload trip which, in

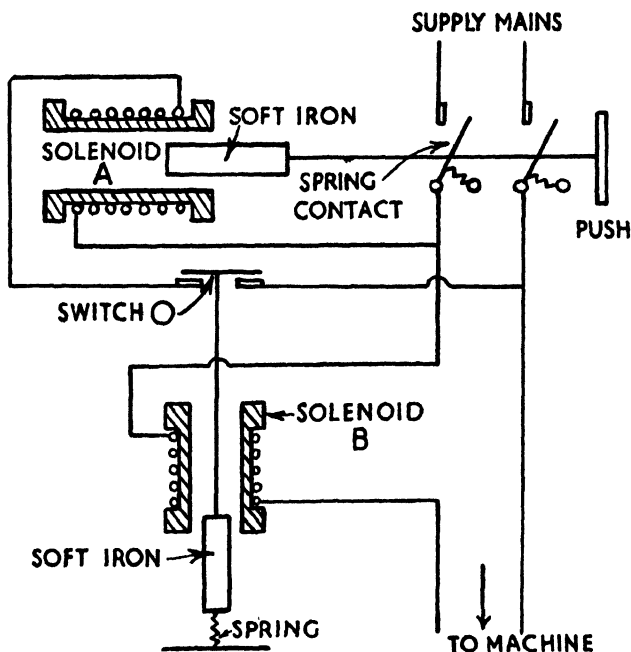


FIG. 105

the event of the machine being overloaded to a dangerous extent, causes tripping of the switch, thus cutting off the supply to the machine and so preventing serious damage.

The overload trip depends on the magnetic effect of a solenoid conveying a current. The solenoid B (Fig. 105) carries full load current and when overloaded attracts the soft-iron core against the action of the spring. This opens the switch O which causes the solenoid A, i.e. the no volts release, to be demagnetised. The circuit is thus opened and has to be remade by manual operation.

Shot-firing Batteries

The main types of shot-firing batteries are (1) batteries which rely for their operation on a contained dry cell and (2) batteries which utilise the effect of an induced E.M.F. when a coil is rotated in a magnetic field.

A diagram and description of a shot-firing battery which is sometimes called an exploder is given below.

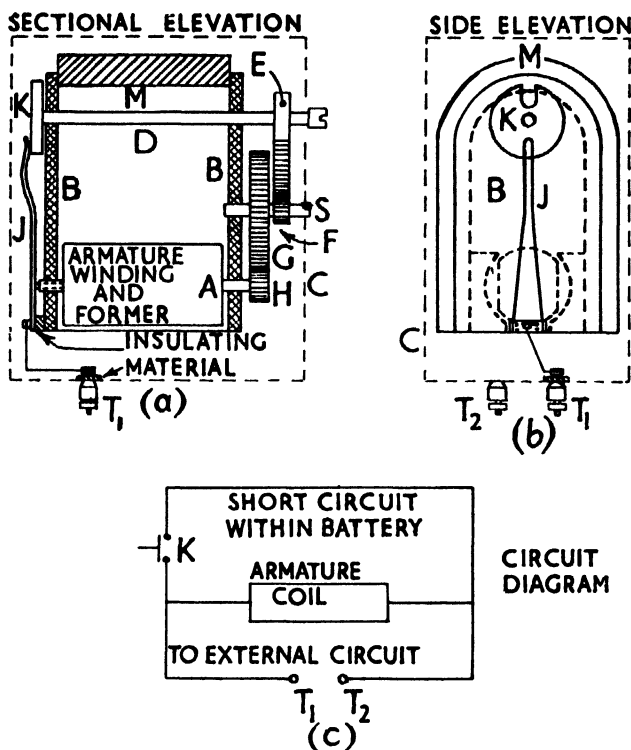


FIG. 106

The battery is provided with a permanent magnet of the horse-shoe type (Fig. 106). Two brass plates *B*, enclosing the magnet *M*, carry the driving and armature shafts, while one of the plates and the battery casing *C* carry a short counter-shaft *S* (Fig. 106a).

The driving shaft *D* carries a sector gear wheel *E* which engages with a pinion *F* on the counter-shaft. A spur wheel *G* carried by the counter-shaft engages the pinion *H* on the arma-

ture shaft A. This system of gears enables the armature to be rotated at a fairly high speed when the driving shaft is turned by means of a removable handle.

The armature carries a winding of copper wire which is provided with a silk covering and when it is rotated between the poles of the permanent magnet, an E.M.F. is induced in it.

The armature winding is arranged with one end insulated from the armature shaft and casing. This end is connected to a terminal T_1 which is insulated from the casing. The other end of the armature winding is connected to the armature shaft and the circuit is completed by means of the shafts and brass plates to the casing and the other terminal T_2 (Fig. 106b). The detonator is connected across the terminals T_1 and T_2 .

The armature winding is short-circuited by means of a spring contact J which makes contact with a brass disc K, mounted on the driving shaft. This short circuit persists for the greater portion of the twist of the handle. Thus the E.M.F. induced in the armature coil is applied to both the short circuit and the external detonator circuit (Fig. 106c).

In the case of the low-tension detonator, the induced E.M.F. in the armature coil produces a sufficient current to fire the detonator. In the case of the high-tension detonator, however, this induced current is insufficient to fire the detonator. The disc K is therefore designed with a slot in it and, near the end of the turn of the handle, the spring contact enters the slot, thus breaking the short circuit. At this stage the induced E.M.F. due to the sudden stopping of the current in the short circuit becomes very considerable and is superimposed on the E.M.F. already applied to the detonator circuit. The current produced is then sufficient to fire the detonator.

A high-tension exploder has a far greater number of turns in the armature coil than a low-tension exploder and the induced current is correspondingly larger.

EXERCISES

1. How would you demonstrate experimentally the difference in the magnetic properties of soft iron and steel?

Describe a mining appliance in which use is made of *either* (a) a temporary magnet, or (b) a permanent magnet. (Min. Sc.; U.L.C.I.)

2. What is meant by the term "Magnetic Declination"? Describe the variations which may occur in the value of the magnetic declination and mention the importance, if any, of these variations in connection with mine surveying. (Min. Sc.; U.L.C.I.)

3. Describe the construction and action of a telephone. What special precautions are necessary in the design and installation of telephones for use in mines? (Min. Sc.; U.L.C.I.)

4. State the principle on which is based the use of the miner's dial for mine surveying. Why is it necessary to indicate on the plan the date of a survey which has been plotted from the magnetic meridian? Describe and explain the effects of a live cable on the needle of a dial set up near it, and state if the effect would remain the same if the dial were moved from place to place in the region of the cable. (Min. Sc.; U.L.C.I.)

5. Give an account of electro-magnetic induction, and describe experiments to illustrate your answer. Give examples of mining electrical machines or apparatus in which electromagnetic induction is of importance. (Min. Sc.; U.L.C.I.)

CHAPTER XIII

OHM'S LAW

POTENTIAL DIFFERENCE

Fig. 107 shows a horizontal tube XY connected to a reservoir R. Vertical tubes project from the tube XY at intervals. The reservoir R contains water which is maintained at a constant level by means of a tap and water flows along the tube XY. The pressures at various points A, C, E, etc., in the horizontal tube are given by the heights of the water columns, viz. AB, CD, EF, etc. The heights of these columns decrease uniformly, which shows that there is a uniform fall of water pressure from X to Y.

In the same manner when an electric current flows through a uniform wire, there is a difference of electric pressure between the ends of the wire and also a uniform fall of electric pressure along the wire. This difference of electric pressure, which is known as potential difference (P.D.), is produced by connecting the ends of the wire to a dynamo, an accumulator, etc. Potential difference is measured in volts by an instrument known as a voltmeter.

CURRENT STRENGTH

Just as the strength of a water current at a given point in a tube is the quantity of water which passes the point per second, so *the strength of an electric current is the quantity of electricity which passes a given point in a wire per second.*

Current strength is measured in amperes by an instrument called an ammeter.

OHM'S LAW

A definite relationship exists between the current in a wire and the potential difference between its ends. This relationship, which was discovered by Ohm, a German scientist, states that *the potential difference between the ends of a conductor is directly proportional to the current flowing in the conductor.*

If AB is the conductor (Fig. 108), I the current strength

and V the potential difference between the ends, we have:

$$\frac{V}{I} = \text{a constant.}$$

The value of this constant is known as the electrical resistance of the conductor.

Thus
$$\frac{V}{I} = R,$$

where V = the potential difference between A and B,
 I = the current in AB,
 and R = the resistance of conductor AB.

Units

The units of potential difference, current and resistance are the volt, the ampere and the ohm respectively.

If $V = 1$ volt and $I = 1$ ampere, then $R = 1$ ohm.

Thus a potential difference of 1 volt maintains a current of 1 ampere in a resistance of 1 ohm.

Example. An electric lamp has a resistance of 1,000 ohms and is placed across the mains, the voltage of which is 230 volts. Find the current in the filament of the lamp.

Using $\frac{V}{I} = R$, we have:

$$V = 230 \text{ volts, } R = 1,000 \text{ ohms}$$

$$\therefore \frac{230}{I} = 1,000$$

$$\therefore I = \frac{230}{1,000} \text{ amp.}$$

$$= 0.23 \text{ amp.}$$

Example. A wire of 30 ohms resistance has a current of 1.5 amperes flowing through it. Find the P.D. between the ends of the wire.

Using $\frac{V}{I} = R$, we have:

$$I = 1.5 \text{ amp., } R = 30 \text{ ohms.}$$

$$\therefore \frac{V}{1.5} = 30$$

$$\therefore V = 1.5 \times 30$$

$$= 45 \text{ volts.}$$

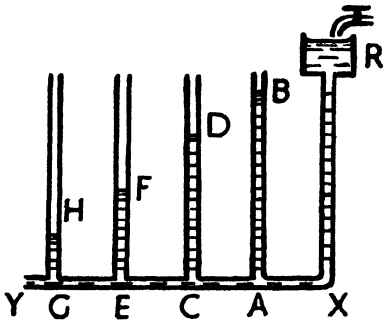


FIG. 107

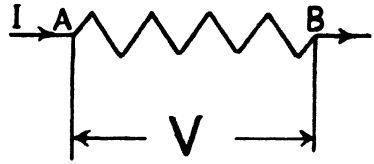


FIG. 108

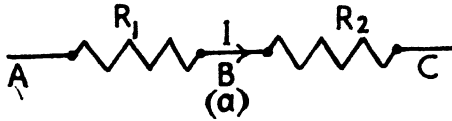


FIG. 109

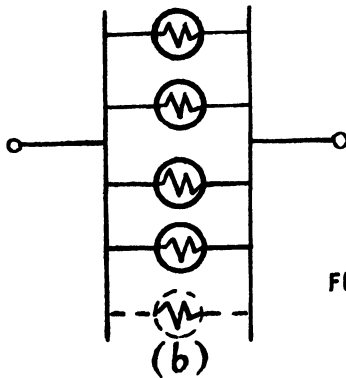
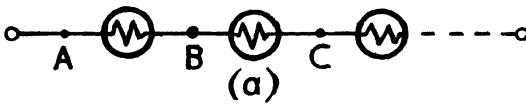
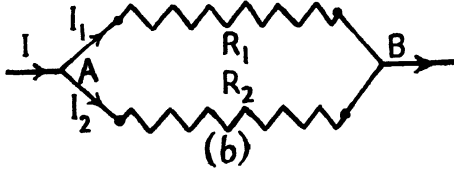


FIG. 110

RESISTANCES IN SERIES AND IN PARALLEL

Series

Fig. 109a shows two resistances in series. In this case the current is the same in each resistance. If R_1 and R_2 are the separate resistances and R is the combined resistance, we have:

$$\text{P.D. between A and C} = \text{P.D. between A and B} + \text{P.D. between B and C.}$$

$$\therefore IR = IR_1 + IR_2$$

$$\therefore R = R_1 + R_2$$

Example. Two coils of resistance 50 ohms and 75 ohms are arranged in series across the 230-volt mains. Find the current in the coils and the P.D. between the ends of the 75-ohm coil.

$$\begin{aligned} \text{Combined resistance} &= 75 + 50 \text{ ohms.} \\ &= 125 \text{ ohms.} \end{aligned}$$

From $\frac{V}{I} = R$, we have:

$$\frac{230}{I} = 125$$

$$\begin{aligned} \therefore I &= \frac{230}{125} \text{ amp.} \\ &= 1.84 \text{ amp.} \end{aligned}$$

$$\begin{aligned} \text{P.D. between ends of 75-ohm coil} &= IR \\ &= 1.84 \times 75 \text{ volts.} \\ &= 138 \text{ volts.} \end{aligned}$$

Parallel

Fig. 109b shows two resistances arranged in parallel. The current I splits up at A into two branch currents, I_1 along the resistance R_1 , and I_2 along the resistance R_2 . These currents recombine at B.

If $V = \text{P.D. between A and B}$, we have:

$$\frac{V}{I_1} = R_1 \text{ or } \frac{V}{R_1} = I_1$$

$$\text{and } \frac{V}{I_2} = R_2 \text{ or } \frac{V}{R_2} = I_2$$

$$\text{Also } \frac{V}{I} = R \text{ or } \frac{V}{R} = I, \text{ where } R \text{ is the combined resistance.}$$

$$\text{But } I = I_1 + I_2$$

$$\therefore \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$$

$$\therefore \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

If three or more resistances are arranged in parallel, the combined resistance R is given by:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{etc.}$$

Example. Two coils of resistance 10 ohms and 15 ohms are arranged (a) in series, (b) in parallel. Find the combined resistance in each case.

(a) The combined resistance R is given by

$$\begin{aligned} R &= R_1 + R_2 \\ &= 10 + 15 \text{ ohms} \\ &= 25 \text{ ohms.} \end{aligned}$$

(b) Let R = the combined resistance.

$$\begin{aligned} \frac{1}{R} &= \frac{1}{10} + \frac{1}{15} \\ &= \frac{3}{30} + \frac{2}{30} \\ &= \frac{5}{30} \end{aligned}$$

$$\therefore R = \frac{30}{5} = 6 \text{ ohms.}$$

Example. Ten lamps, each of 1,000 ohms resistance, are connected across the 230-volt mains (a) in series and (b) in parallel. Find the current in each lamp in each case (Fig. 110a and b).

(a) P.D. across $AB = 1,000I$ volts, where I is the current.

P.D. across $BC = 1,000I$ volts, etc.

$$\therefore 230 = 10 \times 1,000I$$

$$\begin{aligned} \therefore I &= \frac{230}{10,000} \text{ amp.} \\ &= 0.023 \text{ amp.} \end{aligned}$$

(b) In this case each lamp is connected directly across the mains.

$$\text{Hence } \frac{V}{I} = R$$

$$\therefore \frac{230}{I} = 1,000$$

$$\begin{aligned} \therefore I &= \frac{230}{1,000} \\ &= 0.23 \text{ amp.} \end{aligned}$$

The total current taken by the ten lamps is 10×0.23 amp., i.e. 2.3 amp.

Series and Parallel Circuits in Shot-firing Operations

The use of delayed action detonators in shot-firing operations requires that a group of detonators should be connected together in series (Fig. 111a) or in parallel (Fig. 111b). Each

detonator contains a time fuse and the detonators are timed to go off at predetermined instants.

In simultaneous shot-firing operations, the detonators are coupled in series as in Fig. 111a and contain no fuses. The first detonator is coupled to one cable with one of the wires and the last detonator of the round is coupled to the other cable.

Shunts

When only a fraction of the current in a circuit is required to traverse an ammeter a piece of wire, known as a shunt, is placed in parallel with the ammeter (Fig. 112). The length of the shunt wire and consequently its resistance is so chosen that the required fraction of the current passes through the ammeter and the remainder through the shunt. The fall of potential from X to Y is the same whether taken through the ammeter or through the shunt.

Example. An ammeter, reading 0.1 ampere, has a resistance of 0.05 ohm. What shunt must be placed in parallel with the ammeter so that it may read 10 amperes?

Again considering Fig. 112, let r be the resistance of the shunt. The current of 10 amperes is split up at X, and the ammeter only takes 1 ampere.

Hence P.D. between X and Y through ammeter = 1×0.05 volt

and P.D. between X and Y through shunt = $9r$ volt

$$\therefore 9r = 1 \times 0.05$$

$$\therefore r = \frac{0.05}{9} = 0.0056 \text{ ohm.}$$

AMMETERS AND VOLTMETERS

The function of an ammeter is to measure the strength of the current in a circuit. The ammeter is placed in series with the various coils, etc., and its resistance must be very small. Thus the resistance of the circuit is scarcely affected and consequently the presence of the ammeter does not appreciably affect the current. In the last chapter the construction of the moving-coil galvanometer (Fig. 95a) was discussed. A moving-coil ammeter is constructed on similar lines, the only addition being a shunt wire AB (Fig. 113) of low resistance, placed in parallel with the moving coil. This shunt wire reduces the resistance of the instrument to the very small value which is essential in the case of an ammeter.

As we have already seen, the function of a voltmeter is to measure the potential difference between the ends of a conductor. The voltmeter must therefore be placed in parallel with the conductor AB as in Fig. 114, and its resistance must be

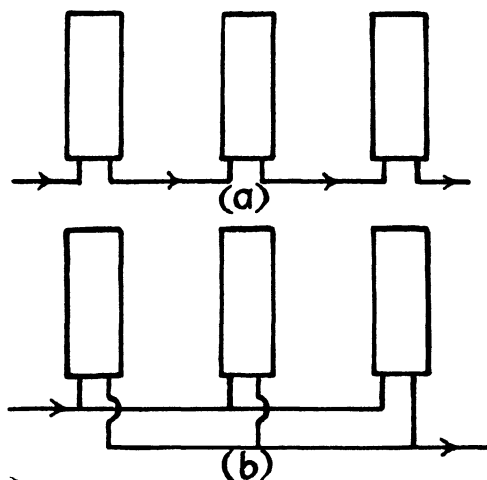


FIG. 111

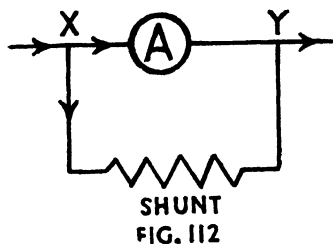


FIG. 112

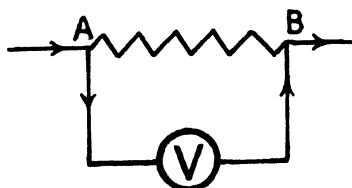


FIG. 114

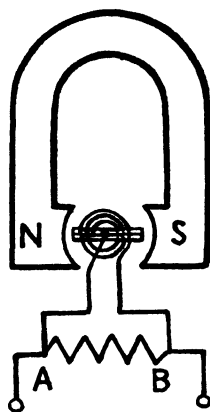


FIG. 113

very high so that the current in the conductor is not materially altered by its presence. The galvanometer shown in Fig. 95a (Ch. XII) may be made into a voltmeter by placing a very high resistance AB in series with the moving coil (Fig. 115).

SPECIFIC RESISTANCE

The resistance of a centimetre cube of a material is known as the specific resistance or resistivity of the material and is measured in ohms per centimetre cube.

Fig. 116a represents a row of l cm. cubes. If s is the specific

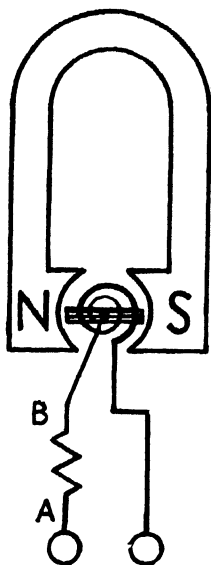


FIG. 115

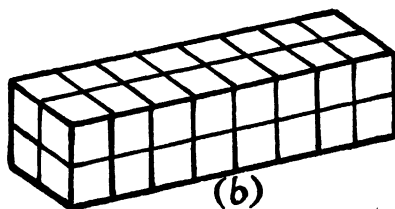
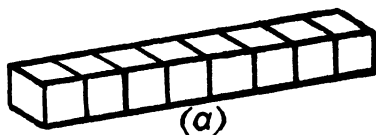


FIG. 116

resistance of the material (i.e. the resistance of each cm. cube), then the resistance of the row of cubes is equal to ls ohms. If we have A rows (Fig. 116b), each row consisting of l cm. cubes, the combined resistance of the A rows is given by R ,

$$\begin{aligned}\text{where } \frac{1}{R} &= \frac{1}{ls} + \frac{1}{ls} + \dots \text{ to } A \text{ terms} \\ &= \frac{A}{ls} \\ \therefore R &= \frac{ls}{A}.\end{aligned}$$

Evidently R varies as l when A and s are constant

and R varies as $\frac{1}{A}$ when l and s are constant.

If we take the inch as the unit of length, the specific resistance is measured in ohms per inch cube.

Example. What is the resistance of a mile of copper wire, if the diameter of the wire is 0.1 inch and the specific resistance 0.00000067 ohm per in. cube?

From $R = \frac{sl}{A}$, we have:

$$\begin{aligned}R &= \frac{0.00000067 \times 1760 \times 36}{\frac{\pi}{4} \times (0.1)^2} \text{ ohms} \\ &= 5.40 \text{ ohms}.\end{aligned}$$

EXERCISES

1. The potential difference between the ends of a wire is 220 volts. If the resistance of the wire is 125 ohms, calculate the current in the wire.

2. A current of 1.5 amperes passes through a wire of resistance 25 ohms. Find the potential difference between the ends of the wire.

3. A lamp requires a current of $\frac{1}{2}$ ampere. If the lamp is to be connected to a 220-volt supply, what must be its resistance? What would be the effect of putting this lamp on a 100-volt supply?

(P.S.T.2.; U.L.C.I.)

4. Current is taken from a 220-volt supply and passes first through a resistance R_1 of 50 ohms and then through a spiral coil R_2 of resistance 5 ohms. What is the reading on an ammeter placed in the circuit?

(P.S.T.2.; U.L.C.I.)

5. What resistance must be connected in series with a coil having a resistance of 60 ohms, if a current of 3 amperes is to flow through the circuit when supplied by mains at 210 volts? (P.S.T.2.; U.L.C.I.)

6. Two wires of resistance 20 and 30 ohms are arranged (a) in series, (b) in parallel. Determine the resistance of the combination in each case.

7. The specific resistance of copper is 0.00000067 ohm per inch cube. Calculate the resistance of a copper wire 100 yards long and 0.060 inch diameter.

8. 1,000 yards of 22 S.W.G. copper wire has a resistance of 39 ohms, the cross-sectional area of the wire being 0.000616 sq. in. Deduce from this the specific resistance or resistivity of copper. (U.L.C.I.)

9. State Ohm's Law, and define the electrical terms you mention.

An electrical measuring instrument, having a resistance of 1 ohm, shows its maximum deflection when a current of 2 amperes is flowing through it. Find (a) what resistance must be coupled in parallel with the instrument so that the maximum deflection will be obtained when the total current in the combined circuit is 10 amperes, (b) what resistance must be coupled in series with the instrument so that the maximum deflection will be obtained when the total pressure across the combined circuit is 100 volts. (Min. Sc.; U.L.C.I.)

CELLS AND BATTERIES

THE COMPLETE CIRCUIT

The Electrolysis of Dilute Sulphuric Acid

Thus Sulphuric Acid = Hydrogen-ion + Sulphon.
(appears at cathode)



151

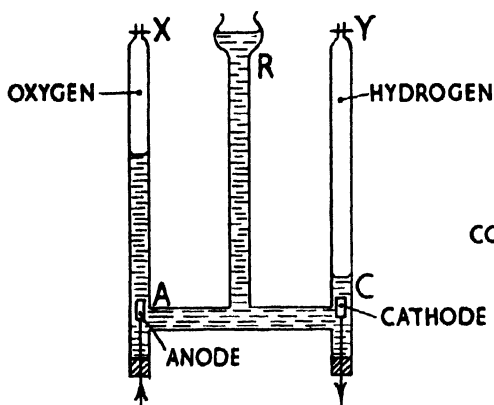


FIG. 117

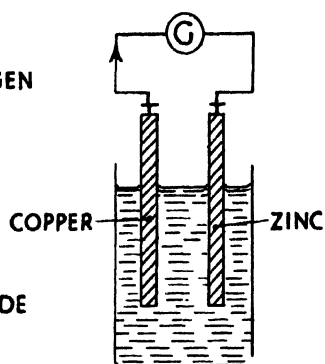


FIG. 118

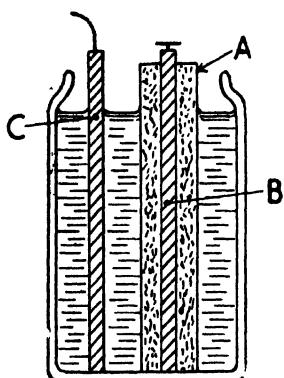


FIG. 119

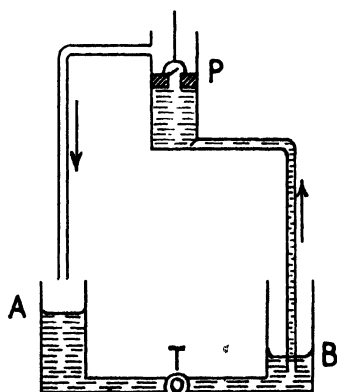
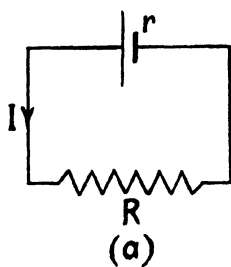
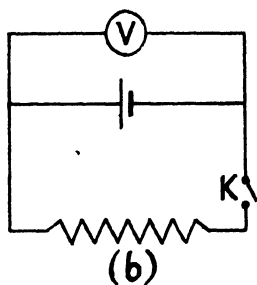


FIG. 120



(a)

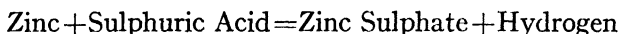


(b)

FIG. 121

If the zinc plate is withdrawn and its surface is rubbed with mercury by means of a piece of cloth, when the plate is replaced in the acid to which a few crystals of potassium bichromate have been added the deflection of the galvanometer remains steady for a much longer period than before.

The above arrangement constitutes a simple cell. A current flows from the copper plate to the zinc plate through the galvanometer and from the zinc to the copper plate through the cell. The terminal by which the current leaves the cell is called the positive terminal and the other is the negative terminal. The chemical reaction is shown below:



The hydrogen produced collects on the copper plate and has the effect of reducing the current, which gradually decreases to zero. This effect is called polarisation and to prevent it a substance such as potassium bichromate which is rich in oxygen is added. The hydrogen is oxidised to water in the manner shown below:

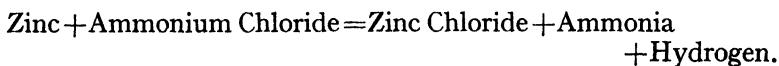


The potassium bichromate is known as the depolarising agent.

Another defect of a simple cell is local action. Local action is the wearing away of the zinc plate due to impurities in the zinc, and it is prevented by amalgamating the plate, that is, by covering it with a coating of mercury. The zinc and the mercury form an amalgam and the defect of local action is practically eliminated.

The Leclanché Cell

The Leclanché cell (Fig. 119) consists of a porous pot A which contains a carbon rod B, surrounded by a mixture of gas carbon and manganese dioxide. The porous pot is contained in a glass vessel and the space between them contains a solution of ammonium chloride (sal-ammoniac). A zinc rod C is immersed in this solution and the zinc and the carbon rods are fitted with screw terminals. When these terminals are connected by a wire a current flows from the carbon (positive) to the zinc (negative) through the wire. The chemical reactions which take place are:



The manganese dioxide is the depolarising agent and supplies the oxygen required to oxidise the hydrogen. Thus we have:



In spite of the fact that a depolarising agent is present, the current gradually decreases. This is because hydrogen is produced at a greater rate than it can be oxidised.

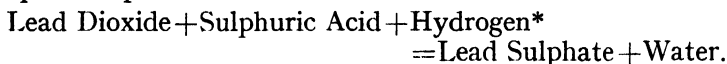
The Leclanché cell is therefore never used when a continuous current is required for a considerable time. For an intermittent current, however, such as that required for an electric bell, it is a most useful cell, because in the intervals between the ringings of the bell, the cell has time to recover.

Leclanché cells are used in the mine for electric bell and signalling circuits.

The Accumulator

The accumulator, or storage cell as it is sometimes called, has a greater practical usage than a Leclanché cell, as it supplies a continuous current over a long period. In its simplest form it consists of two lead plates immersed in dilute sulphuric acid, contained in a vessel generally made of glass or celluloid. The positive plate is covered with lead dioxide, which has a chocolate colour, while the negative plate has a covering of spongy lead, which is slate-coloured. When the terminals attached to the plates are connected by a conductor, a current flows from the positive to the negative terminal through the conductor. In this case the cell is discharging and the chemical reactions taking place are:

At positive plate—



At negative plate—

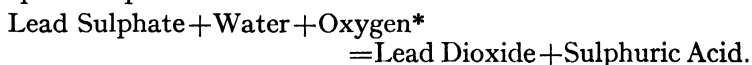


The lead plates become covered with a coating of white lead sulphate and some of the sulphuric acid is used up. This causes the relative density of the acid to fall from 1.27 when fully charged to 1.2 when discharged. In Chapter II we saw how the relative density of the acid could be measured by a small hydrometer and how this test served to show when the cell is run down. The voltage of the cell also decreases from 2.1 volts on full charge to 1.8 volts on discharge.

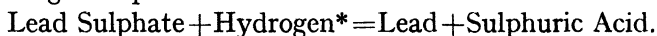
To recharge the cell a current from a direct-current generator

of suitable voltage is passed into the positive terminal of the cell and the following reactions take place:

At positive plate—



At negative plate—



In the process of charging an accumulator, the lead sulphate on the positive plate is converted into lead dioxide and the lead sulphate on the negative plate is changed to spongy lead.

The relative density of the acid increases owing to the formation of more sulphuric acid and the voltage rises to 2.1 volts on full charge.

In the manufacture of accumulators, lead-dissolving acid is added to the sulphuric acid and charging and discharging are repeated many times until the depth of the deposit on the plates is considerably increased. In this method, which is known as the Planté process, the plates are said to be “formed.”

An accumulator can only supply a limited quantity of electricity, depending on its specification. This quantity is known as its capacity and if exceeded the cell becomes damaged. If an accumulator has a capacity of 50 ampere-hours, it is capable of supplying 1 ampere for 50 hours, 2 amperes for 25 hours, etc. If a greater quantity of electricity than specified is taken from the accumulator, excessive sulphating takes place, that is, too much lead sulphate is formed. There is also a safe upper limit to the strength of the current which can be taken from the accumulator.

Dry Cells

Dry cells are usually of the Leclanché type, the sal-ammoniac solution being replaced by a paste which is moistened with sal-ammoniac solution. The glass vessel is replaced by a zinc container which serves as the negative of the cell whereas the porous pot, containing the gas carbon, manganese dioxide and carbon rod, is replaced by a cardboard case. The cell is sealed at the top, a small vent hole being provided.

* During discharge the current leaves at the positive plate, which becomes the cathode of an electrolytic cell, and hydrogen is liberated at this electrode. The current enters at the negative plate, which becomes the anode where oxygen is liberated.

During charging the current enters at the positive plate, which becomes the anode at which oxygen is liberated. The current leaves at the negative plate, which becomes the cathode where hydrogen is liberated.

In mining practice, dry cells are often used instead of the usual fluid cells. These dry cells possess the advantage of portability which enables them to be used in instruments such as the McLuckie methanometer.

ELECTROMOTIVE FORCE

If the tap T (Fig. 120) is open water flows from the vessel A to the vessel B. The water level in A falls, while that in B rises. In order to maintain the difference in water levels the same, the pump P draws water from the vessel B to the vessel A.

A cell functions in a similar manner. We may imagine A and B to represent the positive and the negative plates of the cell respectively, and the difference in level when T is closed to represent the electromotive force of the cell. The tap T when open is analogous to the external resistance which is connected to the terminals of the cell, and the pump P is analogous to the chemical energy of the cell which causes the current to flow from the negative to the positive terminal in the cell.

If R = the external resistance in ohms (Fig. 121a),
 r = the internal resistance of the cell in ohms,
 I = the current in amperes,

and E = the electromotive force of the cell in volts,

then E.M.F. = P.D. to drive the current round the external circuit + P.D. to drive the current through the cell,

i.e. $E = IR + Ir$

or $I = \frac{E}{R + r}$.

This relationship represents Ohm's Law for a complete circuit.

Fig. 121b shows a cell of electromotive force E in series with an external resistance and a plug key K . A voltmeter V is connected to the terminals of the cell. When the key K is open, no current flows through the external resistance and the voltmeter V , which takes an insignificant current, reads the electromotive force (E.M.F.) of the cell. This is the total E.M.F. or the E.M.F. on open circuit. When the key K is closed, a current flows through the external resistance and the voltmeter registers the potential difference required to drive the current through this resistance or the E.M.F. on closed circuit.

Example. A miner's electric lamp is connected across the terminals of a battery of E.M.F. 2.1 volts and internal resistance 0.2 ohm. If the resistance of the lamp filament is 5 ohms, calculate the current in the filament and the P.D. between the terminals of the battery.

We have
$$I = \frac{E}{R + r},$$

where E = E.M.F. of battery in volts,
 R = external resistance in ohms,
 r = internal resistance of battery in ohms.

$$\begin{aligned} \therefore I &= \frac{E}{R + r} = \frac{2.1}{5 + 0.2} \\ &= \frac{2.1}{5.2} = 0.404 \text{ amperes.} \end{aligned}$$

P.D. between terminals of battery = IR .

$$\begin{aligned} &= 0.404 \times 5 \\ &= 2.02 \text{ volts.} \end{aligned}$$

EXERCISES

1. Distinguish between a primary and a secondary cell. Enumerate the common uses of each type at mines. Describe the construction and action of a primary cell commonly used in mines, and indicate how the cell is maintained in good condition. (Min. Sc.; U.L.C.I.)

2. What is meant by the capacity of a battery? State the conditions which must be fulfilled by a battery suitable for use in a miner's electric hand lamp. Compare the advantages and disadvantages of lead-acid and nickel-iron cells for this purpose, and describe, with a sketch, the construction and action of one type of cell. (Min. Sc.; U.L.C.I.)

3. What conditions should be fulfilled by a battery suitable for use in a miner's electric hand lamp? Describe the construction of one type of cell, and indicate the chemical reactions which take place during charge and discharge. (Min. Sc.; U.L.C.I.)

4. A miner's electric lamp is connected across the terminals of a battery of E.M.F. 2.0 volts and internal resistance 2.5 ohms. If the resistance of the lamp filament is 5 ohms, calculate the current in the filament and the P.D. between the terminals of the battery.

5. A 12-volt battery whose resistance is 60 ohms is used to work a telegraph line 8 miles long, the resistance of the line wire being 10 ohms per mile. Calculate the current flowing in the circuit if the telegraph instrument, which is in series in the circuit, has a resistance of 100 ohms. (P.S.T.2.; U.L.C.I.)

CHAPTER XV

HEATING EFFECTS OF CURRENT

INTRODUCTION

It is common knowledge that when an electric current passes through a wire heat is produced. In fact, the heat produced sometimes raises the temperature of the wire to such a value that it becomes incandescent, as in the case of an electric radiator or lamp.

From the Principle of the Conservation of Energy, energy can neither be created nor destroyed, but it can be transformed from one form into another. Thus the appearance of heat in a wire due to the passage of an electric current suggests that energy is expended in maintaining the current and the consequent supply of heat associated with it. This energy comes from the dynamo or from the stored-up energy of the cell to which the wire is connected.

The Joule

The unit of electrical energy is the joule and a joule is the energy consumed when a potential difference of one volt maintains a current of one ampere in a conductor for one second. Thus:

Energy consumed when a P.D. of 1 volt maintains a current of 1 amp. for 1 second = 1 joule.

∴ Energy consumed when a P.D. of V volts maintains a current of 1 amp. for 1 second = V joules.

∴ Energy consumed when a P.D. of V volts maintains a current of I amp. for 1 second = VI joules,

and Energy consumed when a P.D. of V volts maintains a current of I amp. for t seconds = $VI t$ joules.

i.e. $W = VI t$, where W = the energy consumed in joules.

But $V = IR$, where R = the resistance of the conductor.

Hence $W = I^2 R t$

or $W = \frac{V^2 t}{R}$.

But from the mechanical equivalent of heat,

$$1 \text{ calorie} = 4.2 \text{ joules.}$$

Hence if H is the heat produced (expressed in calories) we have

$$H = \frac{VI t}{4.2}$$

$$\text{or} \quad H = \frac{I^2 R t}{4.2}$$

$$\text{or} \quad H = \frac{V^2 t}{4.2 R},$$

where V , I , R and t are expressed in volts, amperes, ohms and seconds respectively.

Example. How much heat is produced per hour in a cable 1,000 ft. long, if the resistance per foot is 0.05 ohm and a current of 5 amperes flows?

$$\begin{aligned} \text{Resistance of cable} &= 1,000 \times 0.05 \text{ ohms} \\ &= 50 \text{ ohms.} \end{aligned}$$

$$\begin{aligned} \text{Heat produced per hour} &= \frac{I^2 R t}{4.2} \text{ calories} \\ &= \frac{5^2 \times 50 \times 60 \times 60}{4.2} \text{ calories} \\ &= 1,071,428 \text{ calories.} \end{aligned}$$

POWER

We have already seen in Chapter V that the power of a machine is the rate at which the machine performs work.

In Electricity, the rate at which a machine generates energy or the rate at which energy is consumed in a circuit is known as the power.

From $W = VI t$, we have:

$$\text{Power} = \frac{W}{t} = VI$$

i.e. $P = VI$, where P is the power.

Power is measured in watts. Thus we have:

$$\text{Watts} = \text{Volts} \times \text{Amperes.}$$

The Watt

If one joule of energy is consumed per second in a circuit, the power of the circuit is a watt.

The kilowatt = 1,000 watts,

and one Horse Power (H.P.) = 746 watts.

Example. A 60-watt lamp is placed across the mains whose voltage is 230 volts. Find the current in the lamp filament.

From $P=VI$, where V, I and P are the voltage, current and power respectively, we have:

$$\begin{aligned} 60 &= 230I \\ \therefore I &= \frac{60}{230} \text{ amp.} \\ &= 0.26 \text{ amp.} \end{aligned}$$

The Board of Trade Unit.

A larger unit of electricity than the joule is the Board of Trade Unit or the Kilowatt-hour, which is the energy consumed in a circuit in one hour when the power is one kilowatt.

$$\begin{aligned} \text{Thus 1 B.O.T. unit} &= 1,000 \left(\frac{\text{joules}}{\text{seconds}} \right) \times 3,600 \text{ seconds.} \\ &= 3,600,000 \text{ joules.} \end{aligned}$$

Example. How long will one unit of electricity maintain a lamp of 100 watts?

$$\begin{aligned} 100 \text{ watts} &= 100 \text{ joules per second.} \\ 1 \text{ unit of electricity} &= 3,600,000 \text{ joules.} \\ \therefore \text{Time} &= \frac{3,600,000}{100} \text{ seconds} \\ &= 36,000 \text{ seconds} \\ &= \frac{36,000}{60 \times 60} \text{ hours} \\ &= 10 \text{ hours.} \end{aligned}$$

Example. In a shaft inset there are 12 lamps arranged in parallel, each lamp taking 0.3 ampere at 110 volts. Calculate the cost of lighting for a period of 100 hours at 2d. per B.O.T. unit.

$$\begin{aligned} \text{Energy consumed per lamp} &= VI \text{ joules} \\ &= 110 \times 0.3 \times 100 \times 60 \times 60 \text{ joules.} \\ \text{Energy consumed by 12 lamps} &= 110 \times 0.3 \times 100 \times 60 \times 60 \times 12 \text{ joules.} \\ \text{Number of B.O.T. units consumed} &= \frac{110 \times 0.3 \times 100 \times 60 \times 60 \times 12}{3,600,000} \\ &= 39.6 \\ \text{Cost of lighting} &= 39.6 \times 2 \text{ pence} \\ &= 79.2 \text{ pence} \\ &= 6s. 7d. \end{aligned}$$

PRACTICAL APPLICATIONS

The heat developed in a conductor due to an electric current is utilised in industry in a variety of ways, but mining practice is mainly concerned with the waste of energy in the cables used in electrical transmission. This energy loss, viz. I^2Rt , where R is the resistance of the cable, I the current and t the time, has to be reduced as far as possible, especially when the electrical energy has to be conveyed considerable distances underground.

In Chapter XII we discussed the use of transformers for stepping-down a voltage of say 2,200 volts for various requirements. High-voltage supply is used in order that the required power (I^2R) may be transmitted with a low current value. This reduces the I^2R loss in the supply cables, since the value of the current is small, and it also enables conductors of smaller diameter to be introduced into the cables with a resulting decrease in the cost of manufacture. The overall effect is a considerable economic saving.

Electric Lamps

If the potential difference between the ends of a wire is gradually increased, the current increases in the same ratio (Ohm's Law). Moreover, the heat produced per second is proportional to the square of the current. Thus as the potential difference increases the heat produced increases at a greater rate. If the wire is composed of platinum or tungsten, which have high melting points, the temperature of the wire increases to such an extent that heat radiations are emitted, then dull red light, then bright red light and, if the temperature rise is sufficiently high, intense white light is emitted. Thus it can be seen that in order to obtain white light, the filament must be made of a metal of very high melting point, because the wire must not melt at a temperature lower than that required for such radiations.

Also at high temperatures metals oxidise, i.e. they combine with the oxygen of the air. This produces disintegration of the filament, which was a serious defect in the earlier types of lamp. To prevent the oxidation of the material of the filament vacuum lamps were invented. But even in vacuum lamps the filament vaporises and ultimately disintegrates. Modern lamps, however, are first evacuated and then filled with some inert gas such as nitrogen or argon. This process practically eliminates disintegration.

In Fig. 122 a gas-filled tungsten lamp is shown. XY is the glass rod, from which radial supports for the filament branch out. The leads P and Q pass from the contact plate C, through the glass rod to the ends of the filament AB.

Fuses

When a steady current passes through a wire, the heat developed raises the temperature of the wire to a steady value, when the heat developed per second is equal to the heat lost

from the surface of the wire per second. The greater the current, the higher is this steady temperature. With wires made of copper of moderately high melting point, the current carried by the wire may increase to such an extent that this steady temperature becomes very considerable. However, with wires made of lead or tin, whose melting points are low, the current may be such that the steady temperature is not reached before the wire melts.

The maximum current which a wire will carry depends mainly on the diameter, the material of which it is composed and the condition of its surface. If we have two wires of the same

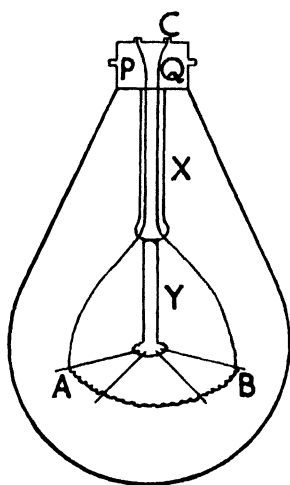


FIG. 122

material and the same surface conditions, the wire with the greater diameter will carry more current than the one of smaller diameter. Also if two wires have the same diameter, the same resistivity and the same surface conditions, the one with the higher melting point will carry more current than the other without being unduly heated.

In an electric circuit where copper wires are in use, large currents may cause the steady temperature mentioned above to be very high and damage to the insulation or even a breakdown may occur. To prevent excessive currents a safety device is employed. This is the principle of the fuse wire. Fuse wires are generally made of tin or an alloy of tin and lead. These wires are inserted in the circuit at some accessible place,

viz. the fuse-box, and melt when the current reaches some predetermined value.

In many mining appliances fuses are utilised as a protection for the electrical gear.

Efficiency of an Electric Motor

Owing to the I^2R loss in the armature coils and other losses, the energy yielded at the pulley of an electric motor per second is less than the energy input per second.

The efficiency of the motor is given by :

$$\text{Efficiency} = \frac{\text{Energy output per second at pulley}}{\text{Energy input per second}}$$

EXERCISES

1. A 60-watt lamp is connected to a 230-volt supply. What current does it take and what is the resistance of the filament?

2. A lamp consumes energy at the rate of 100 watts. How long can it be lit for one B.O.T. unit of electricity?

3. A lamp consumes energy at the rate of 60 watts for 10 hours. What is the cost of the energy at 4d. per B.O.T. unit?

4. In a colliery there are 40 lamps arranged in parallel, each lamp taking 0.3 amp. at 230 volts. Calculate the cost of lighting for a working week of 48 hours at 2d. per B.O.T. unit.

5. An electric motor is receiving 4,500 watts of electrical power and the supply voltage is 230 volts. What is the current, and how many Board of Trade units of electrical energy will it consume if run for 3 hours? If its efficiency be 85 per cent., what will be the horse-power yielded at the pulley? (1 h.p. = 746 watts.)

6. A pump lifts 85 gallons of water per minute against a head of 35 feet. The electric motor driving the pump takes a current of 10 amp. at 200 volts.

Determine (a) the overall efficiency of the set, (b) the number of B.O.T. units taken by the motor in 2 hours, (c) the cost of running the motor for 2 hours at 1½d. per B.O.T. unit. (Min. Sc.; U.L.C.I.)

7. State Joule's Law. How is excessive heating prevented in electric cables?

A cable transmits 60 kilowatts at 500 volts to a motor. If the loss in transmission between motor and generator is 6 per cent. of the power at the generator, calculate the quantity of heat developed in the cable per minute. (Min. Sc.; U.L.C.I.)

8. Power is transmitted by means of a twin-core cable from a generator to a D.C. motor taking 100 h.p. at 500 volts, and situated 1,500 yd. distant. If the cross-sectional area of the cable conductors is 0.15 sq. in. calculate, as a percentage of the power at the generator, the power lost in transmission. (Specific resistance of the cable conductors = 0.66×10^{-6} ohms per cu. in.) (Min. Sc.; U.L.C.I.)

CHAPTER XVI

ILLUMINATION, REFLECTION AND REFRACTION OF LIGHT, LENSES

PHOTOMETRY

Sources of Illumination

We have already discussed the lighting produced when an electric current passes through the filament of a lamp. Prior to this mode of lighting, the chief sources of illumination of an artificial character were the flames from the ordinary candle, the gas jet, the oil lamp, etc., while recently fluorescent lighting has come to the forefront. As far as the miner is concerned, however, the most important sources of illumination are the flame from the oil lamp and the incandescence of the filament in an electric glow lamp.

Now different sources give out different quantities of light, as in the case of an electric lamp, which may give out 32 times as much light as a candle. The amount of light given out by a source is known as the intensity or the illuminating power of the source, and to express this illuminating power it is necessary to choose a unit. The unit agreed upon by all international scientific bodies is known as the standard candle power, which is one-tenth of the illuminating power of a Harcourt Pentane Lamp, adjusted to standard conditions. This lamp burns pentane and is shown in Fig. 123. We are therefore able to express the illuminating power of any source of light in standard candle power.

RECTILINEAR PROPAGATION OF LIGHT

Light travels in straight lines. This can be verified by using the simple apparatus shown in Fig. 124. The apparatus consists of a metallic box L in which an electric lamp is fitted and a small circular hole is cut in one side of the box. S is a white screen and a triangular sheet of metal ABC is held between the screen and the lamp box in a plane parallel to the plane of the screen. When the current in the lamp is switched on, a shadow $A_1 B_1 C_1$ is produced on the screen and the shape of the shadow is exactly similar to that of the metallic sheet.

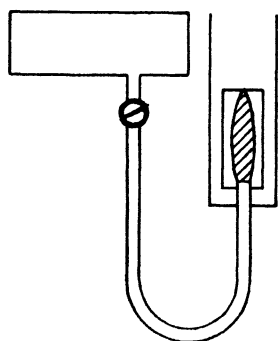


FIG. 123

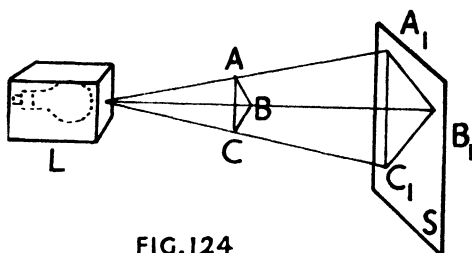


FIG. 124

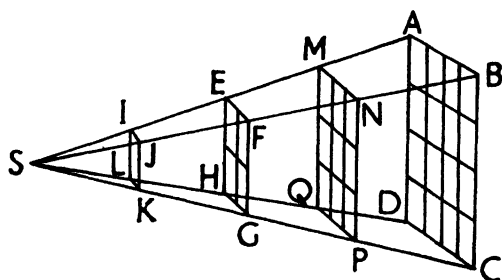


FIG. 125

Intensity of Illumination

The intensity of illumination* on a surface is the quantity of light received by unit area of the surface.

* Intensity of Illumination on a surface is sometimes called the Illumination on the surface.

THE INVERSE SQUARE LAW

Fig. 125 shows a wire frame in the form of a pyramid. The point S represents a point source of light, and the distances of the squares IJKL, EFGH, MNPQ and ABCD from the point S are in the ratio 1 : 2 : 3 : 4. The squares ABCD, MNPQ and EFGH contain 16, 9 and 4 squares respectively, each of the same area as the square IJKL. The amount of light passing through the square EFGH is equal to the amount of light passing through IJKL. Thus the intensity of illumination on the square EFGH is $\frac{1}{4}$, i.e. $\frac{1}{2^2}$, of the intensity of illumination on the square IJKL. Also the amount of light passing through the square ABCD is equal to the quantity of light passing through the square IJKL and thus the intensity of illumination on the square ABCD is $\frac{1}{16}$, i.e. $\frac{1}{4^2}$, of the intensity of illumination on IJKL.

Distance	1	2	3	4
Area	1	2 ²	3 ²	4 ²
Intensity of Illumination	1	$\frac{1}{2^2}$	$\frac{1}{3^2}$	$\frac{1}{4^2}$

The table given above shows that:

$$I \text{ varies as } \frac{1}{d^2},$$

where I is the intensity of illumination and d the distance from the source.

Thus the intensity of illumination at a point due to a small source of light varies inversely as the square of the distance of the point from the source.

RELATION BETWEEN THE ILLUMINATING POWER (CANDLE POWER) OF A SOURCE AND THE INTENSITY OF ILLUMINATION IT PRODUCES AT A POINT

Definition

Unit intensity of illumination is the amount of light received from a source of unit candle power by unit area placed at unit distance from the source and at right angles to the direction of the light.

Thus intensity of illumination due to I.C.P. at 1 foot

$$= 1 \text{ ft.-candle.}$$

∴ intensity of illumination due to P candle power at 1 foot

$$= P \text{ ft.-candles,}$$

and intensity of illumination due to P candle power at d feet

$$= \frac{P}{d^2} \text{ ft.-candles,}$$

i.e. $I = \frac{P}{d^2}$, where I = the intensity of illumination.

Example. What is the intensity of illumination due to a miner's safety lamp, of candle power 1.6, at a distance of 3 feet from the lamp?

We have $I = \frac{P}{d^2}$,

where

P = candle power,

d = distance in feet,

and

I = intensity of illumination in ft.-candles.

∴ $I = \frac{1.6}{3^2}$ ft.-candle

$$= 0.177 \text{ ft.-candle.}$$

MODERN UNITS

In recent years, a different approach to the theory of photometry has been made and new units have been defined.

Solid Angle

Unit solid angle is the angle subtended at the centre of a sphere by an area of the surface equal to the radius squared. Hence the total solid angle at a point (i.e. the centre of the sphere) is equal to $\frac{4\pi r^2}{r^2}$, i.e. 4π .

The Lumen

The unit of light quantity in the modern theory is the lumen, which is the quantity of light given out by a source of one candle power per unit solid angle. Thus if a source has an intensity or illuminating power of P candle power, it gives out P lumens per unit solid angle or $4\pi P$ lumens in all directions.

The Intensity of Illumination or the Illumination at a Point

The intensity of illumination at a point at a distance of d cm. from a source of P candle power (i.e. P lumens per unit solid angle)

$$\begin{aligned} &= \frac{4\pi P \text{ (lumens)}}{4\pi d^2 \text{ (sq. cm.)}} \\ &= \frac{P}{d^2} \text{ lumens per sq. cm.} \end{aligned}$$

If the distances are measured in feet, we have:

$$\begin{aligned}\text{Intensity of illumination} &= \frac{4\pi P \text{ (lumens)}}{4\pi d^2 \text{ (sq. ft.)}} \\ &= \frac{P}{d^2} \text{ lumens per sq. ft.}\end{aligned}$$

Thus it can be seen that the intensity of illumination at a point can either be expressed in lumens per sq. cm. or in cm.-candles when the distance is measured in centimetres, and in lumens per sq. ft. or in ft.-candles when the distance is measured in feet.

PHOTOMETERS

Rumford's Photometer

Suppose two lamps are placed, one at A and the other at B (Fig. 126a), and a cylindrical rod R is placed in front of a white screen CD. The lamp at A and the rod R produce a shadow XZ and the lamp at B produces a shadow of the rod at XY. When the position of the rod and the distances of the lamps are adjusted the two shadows can be made to touch at X, and when the line of demarcation between the shadows disappears the two intensities of illumination are the same. The portions XY and XZ are illuminated by the lamps A and B respectively. For equal intensities we have:

$$\frac{P_1}{d_1^2} = \frac{P_2}{d_2^2},$$

where

P_1 = candle power of A

and

P_2 = candle power of B.

If the lamp A has a known candle power, then the candle power (P_2) of B can be calculated.

Rumford's shadow photometer is shown in Fig. 126b.

Example. A standard lamp of 32 candle power is placed at a distance of 3.5 feet from the screen of a photometer. A lamp of unknown candle power, placed at 1.5 ft. from the screen, produces the same intensity of illumination. Find the candle power of this lamp.

Let x = unknown candle power of lamp.

Intensity of illumination on the screen due to 32 c.p. = $\frac{32}{(3.5)^2}$ ft.-candles

Intensity of illumination on the screen due to x c.p. = $\frac{x}{(1.5)^2}$ ft.-candles

$$\therefore \frac{x}{(1.5)^2} = \frac{32}{(3.5)^2}$$

$$\begin{aligned}\therefore x &= 32 \times \frac{1.5^2}{3.5^2} \\ &= 5.88 \text{ c.}\end{aligned}$$

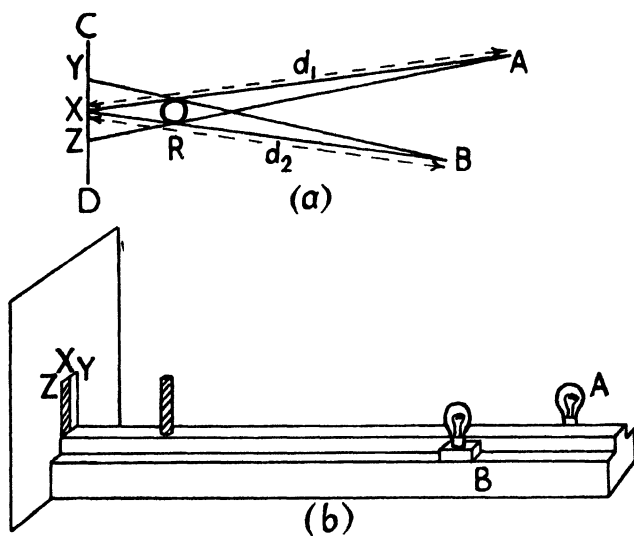


FIG. 126

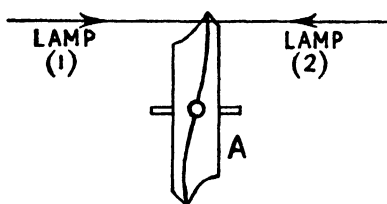


FIG. 127

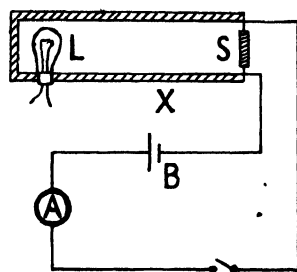
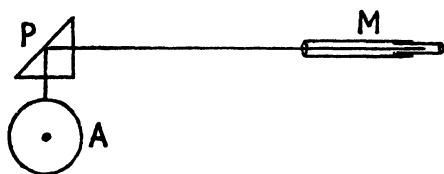


FIG. 128



The Flicker Photometer

In the flicker photometer (Fig. 127) the screen consists of a plaster of Paris cylinder A with a bevelled edge. The axis of the cylinder is parallel to the line joining the two lamps, the candle powers of which have to be compared. The light from one lamp falls on one side of the bevelled edge and the light from the other lamp falls on the other side. A microscope M and a total reflecting prism P (see p. 176) are used for viewing the edges and the cylinder is rotated by clockwork. During one half of a revolution one side of the bevelled edge is seen in the focal plane of the microscope, and during the other half the other side is seen. If the lamps do not give equal illuminations on the two sides, flickering will result. The distances of the lamps are adjusted so that flickering ceases and then the illuminations are equal. The usual formula $\frac{P_1}{d_1^2} = \frac{P_2}{d_2^2}$ is then used.

This photometer is suitable for comparing the candle powers of two lamps which emit light of different colours.

Selenium Cell Photometers

When a beam of light is incident on a strip of selenium, the resistance of the selenium changes, and if the selenium strip is in series with a battery and a suitable ammeter, a change in the ammeter reading is recorded.

This principle is applied in the photometer shown in Fig. 128. A casing X is closed at one end and at the other end the strip of selenium S, fitted with terminals, is placed. An opening for the lamp L is situated near the closed end of the casing. Since the selenium strip takes the place of the eye in estimating the quantity of light, it is imperative to allow only those radiations to which the normal eye is sensitive to be incident on the strip. Hence a light filter which transmits only the required radiations is placed in front of the selenium strip. The strip of selenium and the filter constitute the cell. The selenium cell S is placed in series with a battery B and a sensitive ammeter A. A current flows through the selenium before the lamp is switched on and the reading of the pointer on the ammeter scale is marked zero. Lamps of known candle power are placed in position and the corresponding deflections of the pointer when the lamps are switched on are marked to read these known candle powers. In this way the ammeter scale is calibrated, and if a lamp of unknown candle power is placed in position, when the lamp is switched on, the calibrated scale gives its candle power directly.

There are two important disadvantages of this method. In the first place, it is essential to keep the battery fully charged so that the pointer is always opposite the zero of the scale before the lamp is switched on. Secondly, calibration methods have not proved too successful, owing to "fatigue" which develops in the selenium.

The photometer (Fig. 129) which is about to be described depends on (1) the selenium cell principle and (2) the flicker photometer principle. The photometer head is in the form of an enclosed box, containing two right-angled isosceles reflecting prisms (see p. 176) which are arranged, as shown, opposite apertures in the sides of the box. Light from the standard lamp X is incident on the prism P, which reflects the light upon the selenium cell LM,* and light from the lamp Y under test is reflected by the prism Q upon the space MN. The selenium cell, which is in series with a battery B and a sensitive ammeter A, is oscillated backwards and forwards, by clockwork, between the positions LM and MN. Thus the selenium cell receives light from one lamp and then from the other. If the illuminations due to the two lamps are different, there is a fluctuation in the current which is shown by a flickering of the ammeter pointer. But if the illuminations are the same the flickering ceases. Thus the distances of the lamps are adjusted to give no flickering of the pointer and then the formula $\frac{P_1}{d_1^2} = \frac{P_2}{d_2^2}$ can be applied,

where P_1 = the candle power of the standard lamp
and P_2 = the candle power of the lamp under test.

MEAN HORIZONTAL CANDLE POWER (M.H.C.P.)

The candle power of a lamp in various directions is shown in Fig. 130a. The candle power in each direction is marked on the diagram and when the points are joined the horizontal distribution curve of the lamp is obtained.

In most cases the candle power is nearly always the same in all directions and it is more accurate to plot candle power vertically against angle horizontally (Fig. 130b). The mean horizontal candle power (M.H.C.P.) is then obtained by finding the mean ordinate.

MINER'S LAMPS

The flame safety lamp which is used mainly in testing for methane has already been discussed in Chapter X. Lamps used for illumination are of two types, the oil lamp and the electric

* The cell is fitted with a light filter.

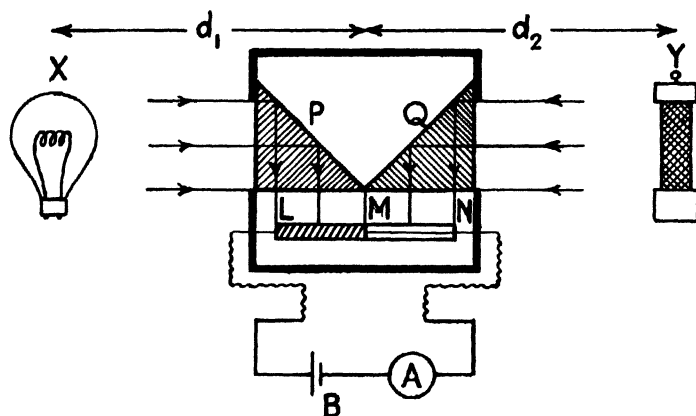


FIG. 129

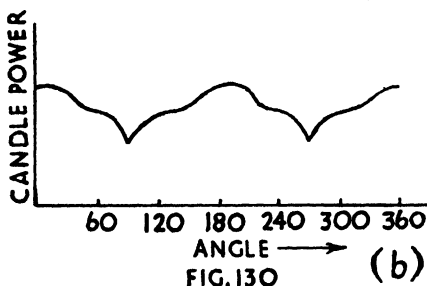
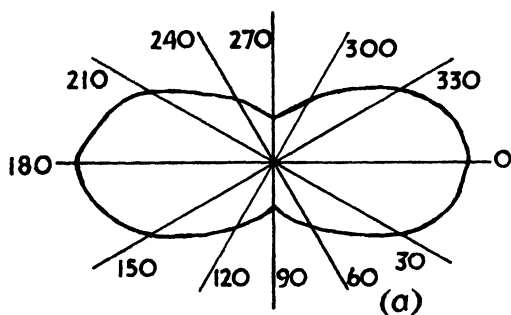


FIG. 130

lamp. These electric lamps, which derive their current from small batteries, have comparatively low candle powers, which become smaller after the lamps have been in use for some time.

LIGHTING IN MINES

The use of electric lighting underground has received considerable attention and in recent years marked improvements have been made. The introduction of miners' electric hand lamps and cap lamps has provided much improved lighting conditions which in turn have helped to reduce the number of cases of nystagmus and have also aided the efforts to obtain safer working conditions. The provision of general lighting underground at shaft insets and other places has increased the standard of lighting and has resulted in increased safety and efficiency. The whitening of roadways (roofs and sides) at positions where general lighting was installed has improved the efficiency of lighting, since the rays of light are reflected to a greater extent from a white surface than from a black surface. The Coal Mines (Lighting) General Regulations, May 17th, 1947, indicate the importance of methods and standards of lighting and also indicate the more recent efforts to improve further the standard of lighting underground:

Provision of general lighting at the coal face and the use of fluorescent lighting are in the experimental stage.

REFLECTION AT PLANE SURFACES

To illustrate the reflection of light, an arrangement is required which gives a thin parallel beam of light. Such an arrangement is the lamp-box (Fig. 131), which consists of a metallic box A with a slit S cut in one side. A suitable cylindrical lens is placed in a support just in front of the slit and a lamp with a frosted globe is placed in position in the box. By means of this arrangement a strong parallel beam of light issues from the slit.

If a plane mirror XY is supported on a sheet of drawing paper by means of two wooden blocks (Fig. 132) and a beam of light from a lamp-box is incident on the mirror at the point B, the beam is reflected along BC. If the points S, B, C and the trace of the mirror are marked and the lines SB, BC and the normal BN are drawn, the angles SBN and CBN are found to be equal. A set of results is shown below.

$\angle \text{SBN}$	$\angle \text{CBN}$
35°	35°
48°	48°
61°	61°

The beam SB is called the incident beam, BC the reflected beam and the angles SBN and CBN are the angles of incidence and reflection respectively.

Laws of Reflection at Plane Surfaces

- (1) The incident ray, the reflected ray and the normal to the mirror at the point of incidence are in the same plane.
- (2) The angle of incidence is equal to the angle of reflection.

Position of the Image due to a Small Object in a Plane Mirror

Fig. 133 represents a plane mirror XY, supported vertically on a sheet of paper, with a pin inserted at O. If pins are inserted at A and B in line with the image of O, and at C and D, also in line with the image of O, the image of O is at the point of intersection of AB and DC, i.e. at I. If the trace of the mirror XY is drawn and I and O are joined, it will be found that IN is equal to ON and that IO is at right angles to XY.

Thus we can deduce that (1) the line joining the image and the object is at right angles to the mirror and (2) the distance of the image behind the mirror is equal to the distance of the object in front.

THE OPTICAL SQUARE

A plan of the optical square is shown in Fig. 134. This instrument is used in surveying for setting out right angles and consists of an enclosed cylindrical housing inside of which are two plane mirrors A and M. The half-silvered mirror A is mounted rigidly at an angle of 60° with the line of sight S_1S_2 , while the mirror M is mounted so that it is capable of rotation about a vertical axis and it is adjusted by a screw attachment to be at an angle of 45° with the mirror A.

On viewing one object O_1 directly through the unsilvered portion of the mirror A, the other object O_2 is adjusted until the images of the two objects are coincident (see inset). Then the lines drawn from both objects O_1 and O_2 to the instrument station are at right angles to each other. The rays, with their inclinations to the mirrors, are shown in the diagram.

REFRACTION AT PLANE SURFACES

If a lamp-box L is placed on a sheet of white paper and a rectangular slab of glass is placed in the path of the beam IO, it will be noticed that the incident beam changes its direction, i.e. suffers refraction as it enters the glass, and again changes

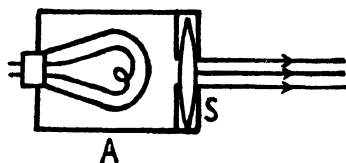


FIG. 131

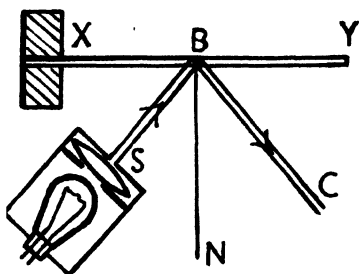


FIG. 132

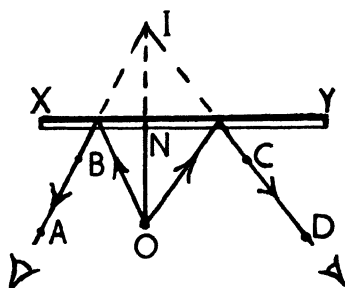
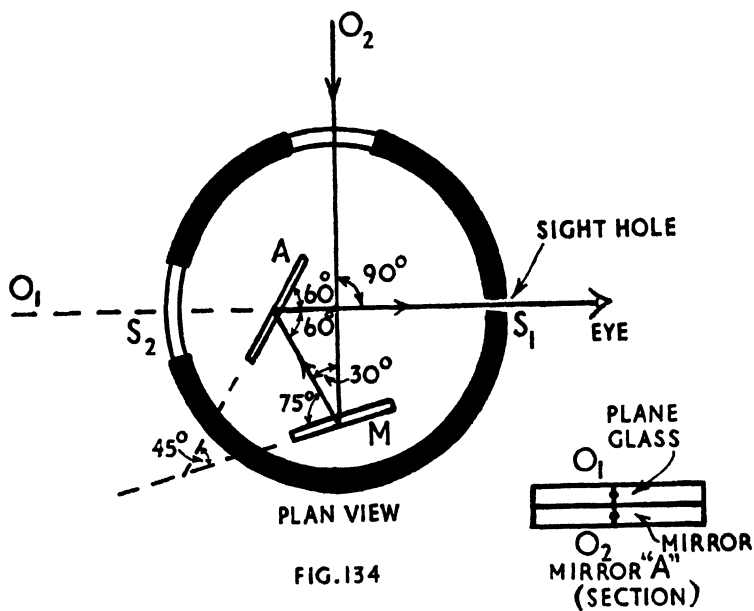


FIG. 133



direction at the second surface (Fig. 135a). But if the incident beam is at right angles to the surface of the slab, the ray passes through the slab undeviated (Fig. 135b).

In Fig. 135a, IO is the incident ray at the air/glass surface, NOM is the normal at O and the angles NOI and O_1OM are the angles of incidence and refraction respectively. Also OO_1 is the incident ray at the glass/air surface, $M_1O_1N_1$ is the normal at O_1 and OR is the refracted ray.

The following deductions can be made:

(1) When a ray of light passes from air to glass, the ray is bent towards the normal in the glass, except in the case when the incident ray is at right angles to the surface, and when a ray of light passes from glass to air, it is bent away from the normal in the air.

(2) The ray O_1R is parallel to the ray IO and a ray of light passing through a parallel slab of glass is undeviated (Fig. 135a).

(3) When a ray of light strikes a plane surface of glass at right angles, it continues along the same line undeviated (Fig. 135b).

Deviation of a Ray of Light through a Triangular Prism

If a triangular slab of glass ABC is placed in the path of a beam of light from a lamp-box, as shown in Fig. 136, the beam changes direction at each surface. IE is the incident ray, EF the refracted ray, and FR the emergent ray. NEO and MFO are the normals at E and F respectively, while the angles NEI, MFR and TSR are the angles of incidence, emergence and deviation respectively.

Total Reflecting Prisms

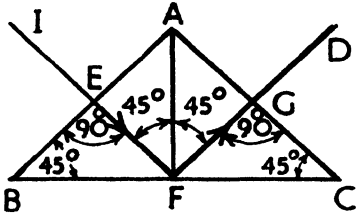
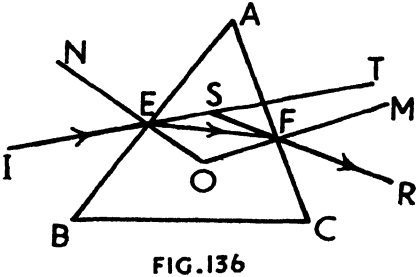
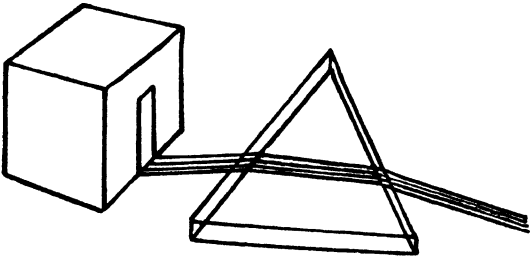
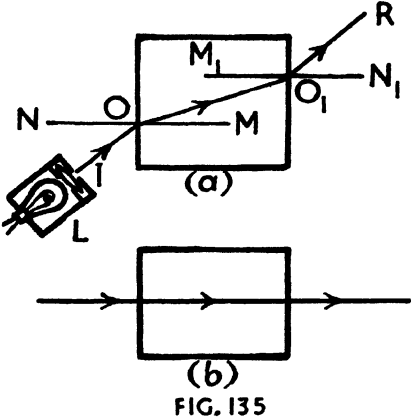
In Fig. 137 ABC represents a right-angled isosceles prism, the angles A, B and C being 90° , 45° and 45° respectively, and AF is the perpendicular drawn from A upon BC. If IE is an incident ray at right angles to the surface AB and directed towards F, this ray continues undeviated along EF and is reflected along FG where the angle EFA is equal to the angle AFG.

$$\text{Now} \quad \angle BFE = 180^\circ - 90^\circ - 45^\circ = 45^\circ.$$

$$\text{Hence} \quad \angle EFA = 45^\circ = \angle AFG.$$

$$\text{Also} \quad \angle GFC = 90^\circ - 45^\circ = 45^\circ.$$

$$\begin{aligned} \text{Hence} \quad \angle FGC &= 180^\circ - 45^\circ - 45^\circ \\ &= 90^\circ. \end{aligned}$$



Hence the ray FG strikes the surface AC at right angles and continues along GD undeviated.

The principle of the total reflecting prism is employed in many optical instruments used in mine surveying.

LENSES

A lens is made of transparent material and it is bounded by spherical surfaces. If C_1 and C_2 are the centres of curvature of the faces, the line C_1C_2 is known as the Principal Axis and it passes through the point P which is called the Optical Centre of the lens (Fig. 138a)

Suppose a slab is cut out of the centre of the lens and that the slab is divided into sections (Fig. 138b). Each section, except the centre one, acts as a triangular prism and deviates rays of light. In the case of the central section, a ray of light coincident with the principal axis passes through the section undeviated. Also rays of light parallel to the principal axis of the lens are deviated by the lens through the point F, which is known as the Principal Focus. The distance between the principal focus and the optical centre of the lens is known as the *Focal Length*.

The lens considered above is a converging or convex lens, since it converges parallel rays to a point. Fig. 138c shows a diverging or concave lens which diverges rays parallel to the principal axis. The diverging rays appear to proceed from the principal focus F.

Object and Image for a Convex Lens

Let P be the optical centre of the lens (Fig. 139), F the principal focus, and OPF the principal axis. Let AOB be an object at right angles to the principal axis. The ray AD, which is parallel to the principal axis, is refracted through the point F and, since the central portion of the lens may be regarded as a thin parallel slab, the ray AP passes through the optical centre of the lens undeviated. Hence the image of A is on DF produced and is also on AP produced. Thus the image of the point A is at A_1 . Similarly the image of B is at B_1 . Thus A_1B_1 is the image of the object AB and is inverted.

Using the construction already described, Fig. 140 shows the size and position of the image due to an object placed at various distances from the lens. As the distance of the object from the lens decreases, the corresponding distance of the image increases.

In the diagram shown (p. 180) the images are real as the actual rays pass through them. They can be projected on a screen and are inverted.

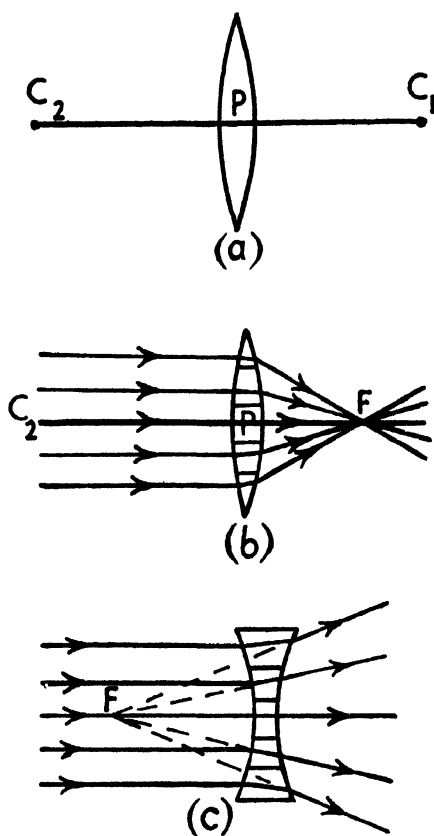


FIG. 138

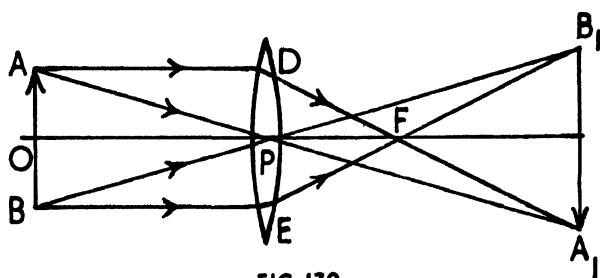


FIG. 139

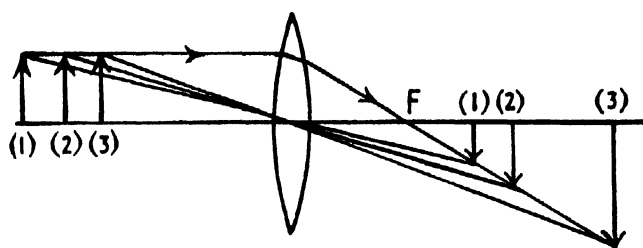


FIG. 140

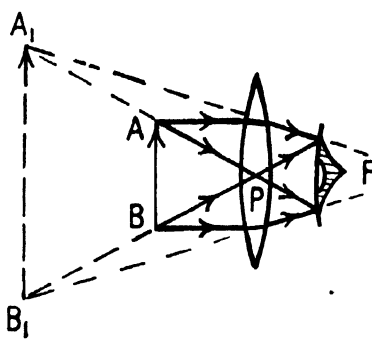


FIG. 141

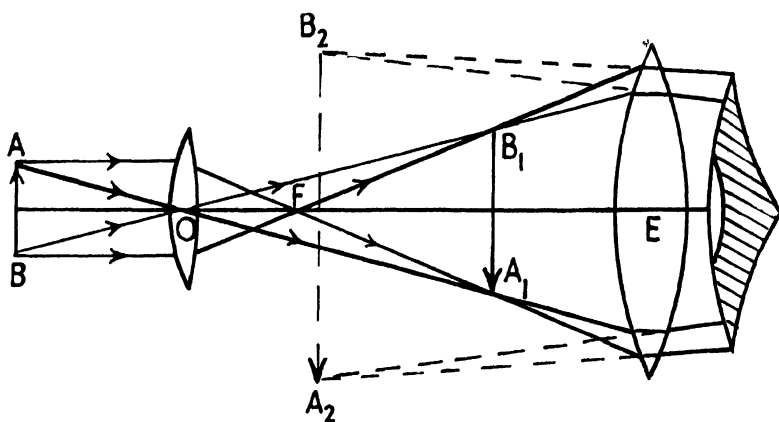


FIG. 142

If the distance of the object from the lens is less than the focal length PF , we obtain the adjoining ray diagram (Fig. 141). It will be noticed that rays from A and B after leaving the lens are diverged and, when produced backwards, form an erect, enlarged image A_1B_1 . If the eye is placed in the position shown, we obtain the ray diagram for a simple microscope. The image is virtual, since the actual rays do not pass through it.

THE COMPOUND MICROSCOPE

A compound microscope consists of two lenses, the objective O and the eyepiece E . The object which is to be viewed, viz. AB (Fig. 142), is placed near the objective, at a distance slightly

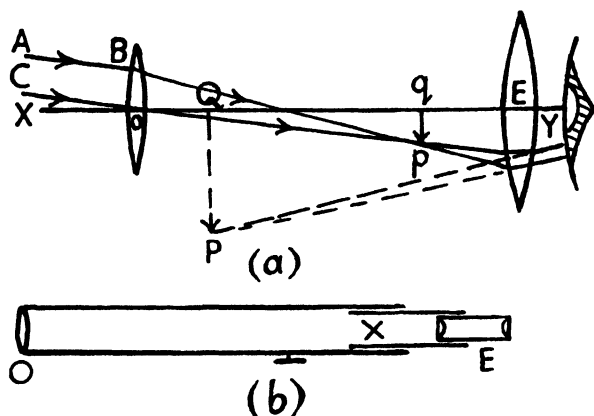


FIG. 143

greater than its focal length OF . A real inverted image A_1B_1 is produced. This image is formed just within the principal focus of the eyepiece E and a final virtual image A_2B_2 is produced. The position of the image A_2B_2 is adjusted by means of the rack and pinion of the instrument until it is clearly seen at the least distance of distinct vision, viz. 25 cm. from the normal eye.

The compound microscope is used by geologists for examining rock and coal sections mounted on slides.

THE TELESCOPE

The telescope (Fig. 143a), which is used for viewing distant objects, consists of two lenses, the objective O and the eyepiece E , XY being the principal axis of the system. AB and CO represent two parallel rays from a point on the edge of a

distant object, removed from the principal axis, and a real image pq is formed by the objective O. The image just comes within the principal focus of the eyepiece E and a final virtual image PQ is produced at the least distance of distinct vision. The image is inverted.

Telescopes are used in many surveying instruments such as the theodolite, sextant, etc. The telescope of the theodolite is shown in Fig. 143b. The eyepiece E is focussed on the cross wires X by adjusting the tube in which its lenses are mounted. The telescope is then turned towards the distant object and the distance between the objective and the eyepiece is adjusted by a rack and pinion until a clear image of the distant object is obtained on the cross wires.

EXERCISES

1. Explain the following terms: foot-candle, candle power, mean horizontal candle power. Describe how the mean horizontal candle power of a miner's lamp may be determined. (Min. Sc.; U.L.C.I.)

2. State the principles relating to the reflection and refraction of light. How is a uniform distribution of light obtained from an electric safety lamp? (Min. Sc.; U.L.C.I.)

3. What is the difference between reflection and refraction of light? Make sketches to illustrate how light is refracted in its passage through (a) a glass plate, (b) a prism, and (c) a double-convex lens. (Min. Sc.; U.L.C.I.)

4. Sketch any type of photometer you have seen, and explain how it is used to compare the candle powers of two lamps. (Min. Sc.; U.L.C.I.)

5. What is meant by the term "principal focus" as applied to a convex lens?

A convex lens is used to produce an image of a blue print. Draw a diagram showing how an image magnified three times may be produced on a screen. (Min. Sc.; U.L.C.I.)

6. Describe some form of photometer, and explain how you would use it to find the candle power of a miner's electric lamp.

What is the intensity of illumination due to a lamp of 1.5 candle power, at a distance of 3 ft. from the lamp? (Min. Sc.; U.L.C.I.)

7. Draw a diagram to show the refraction of a ray of light through (a) a slab of glass with parallel sides, (b) a triangular glass prism, and (c) a bi-convex lens. Also, draw a diagram which shows how the eye sees an object through a convex lens, as in the case of a simple magnifying glass. (Min. Sc.; U.L.C.I.)

8. What is meant by "mean horizontal candle power"?

In a photometer a miner's electric lamp, placed at a distance of 20 in. from the screen, produces the same intensity of illumination as a standard lamp of 12.5 candle power, placed at a distance of 60 in. from the screen. What is the candle power of the miner's lamp?

(Min. Sc.; U.L.C.I.)

9. State the law of reflection of light at a plane reflecting surface.

A beam of light makes an angle of incidence of 30° on a plane mirror. If the incident beam remains fixed and the mirror is rotated through an angle of 17° , find, by calculation or by drawing, the angle through which the reflected ray is rotated. (Min. Sc.; U.L.C.I.)

10. What is meant by (a) candle power, and (b) intensity of illumination?

A standard lamp of candle power 16 is placed at a distance of 6 ft. from a screen. What is the intensity of illumination on the screen? A flame safety lamp, placed at a distance of 2 ft. from the screen, produces the same intensity of illumination. What is the candle power of the safety lamp? (Min. Sc.; U.L.C.I.)

CHAPTER XVII

THE CHEMISTRY OF AIR

INTRODUCTION

Having studied the atmosphere with regard to its weight and pressure, we shall now consider it from the point of view of its chemical composition. What are the gases which constitute the atmosphere and in what proportions do these gases exist? When these questions have been answered we shall then proceed further and study the composition of mine air. How does the composition of mine air differ from that of ordinary air? What are the dangerous and obnoxious gases in mine air and what are the statutory limits for these gases, consistent with the safety of the miner?

The Heating of Metals in Air

If a piece of copper foil is placed in a porcelain crucible which rests on a porcelain triangle, standing on a tripod, and the crucible is heated strongly, after a time it will be noticed that the copper is coated with a black substance. If the process is repeated with magnesium and then with lead these substances become coated with a white and a grey powdery substance respectively.

If the experiment with the magnesium is repeated by first weighing the crucible and magnesium complete with lid, and if the crucible is heated with a small space left for the air to enter, after allowing to cool a gain in weight is noticed. The small space allows air to enter the crucible but prevents the products of combustion from escaping.

Evidently the magnesium combines with some constituent of the air. Now copper, lead and magnesium are metals and when heated strongly in air they combine with oxygen, one of its constituents, producing black copper oxide from copper, grey lead oxide from lead and white magnesium oxide from magnesium. The metals are said to oxidise and the process is known as oxidation.

The Percentage Composition of the Air by Volume

Fig. 144 shows a uniform tube about 40 cm. long, 1.5 cm. in diameter and closed at one end. The tube contains a small

quantity of water which occupies 1 cm. of its length. If the thumb is placed over the open end, the tube can be supported in a stand with this end underneath the surface of water in a trough. If the water levels in the trough and the tube are adjusted to be the same, the length of the air column in the tube may be measured at atmospheric pressure.

The diagram also shows a rubber stopper, fitted with a small glass container in which are placed a few pieces of solid pyrogallol together with one or two pellets of sodium hydroxide. This mixture is known as alkaline pyrogallol.

If the stopper is inserted in the tube, with its end still under water, and the tube is withdrawn and shaken vigorously, the oxygen of the air is absorbed by the alkaline pyrogallol.

When the end of the tube with the stopper is again placed under the water and the stopper is removed, water rises up the tube. If the water levels in the tube and trough are adjusted to be the same so as to reduce the volume of the remaining gas to atmospheric pressure, it will be found that the gas occupies four-fifths of the original volume of the air column. Thus one-fifth of the air by volume consists of oxygen while the remaining four-fifths consists almost entirely of a gas known as nitrogen.

The Rusting of Iron

Fig. 145 shows a small muslin bag, containing iron filings moistened with water and fastened to the end of a knitting needle. If the bag is placed in a gas jar which rests on a beehive shelf in a trough containing water, it will be found that, after allowing the apparatus to stand for a few weeks, the water has risen one-fifth of the length of the jar and the filings have rusted. Actually the iron combines with the oxygen of the air, but this process, which is known as rusting, is much slower than actual burning.

When the jar is removed from the trough and a lighted splint is placed inside, the flame is immediately extinguished. This shows that the remaining gas, nitrogen, does not support burning.

PHYSICAL AND CHEMICAL CHANGES

Ice, water and steam are three states of the same substance and the state is determined by the temperature. The change from one state to another is known as a physical change and there is no alteration in the weight of the substance.

The action of heat on a copper rod, so long as the temperature

does not exceed a certain value, simply causes an increase in length and this is a physical change. But if the temperature is high enough, the copper rod becomes coated with a black tarnish known as copper oxide and in this case a different substance is produced. Such a change is known as a chemical change, and as we have seen in the experiment on the burning of magnesium, it is accompanied by a change in weight.

Elements

An element is a simple substance which cannot be decomposed into other substances by ordinary chemical or physical processes. Elements are generally classified into metals and non-metals. Thus copper, iron, aluminium, zinc, magnesium, etc., are metallic elements, whereas oxygen, nitrogen, carbon, sulphur, etc., are non-metallic elements.

Compounds

In addition to elements there are other substances which are more or less complex. These substances are composed of two or more elements in chemical combination and are known as chemical compounds. A chemical compound is entirely different in properties from the elements of which it is composed. Taking copper oxide as an example, if this substance is divided into small particles, each particle still consists of copper oxide, and however far the sub-division is carried there is no alteration in the composition of the substance.

LAW OF DEFINITE PROPORTIONS

If the experiment on the burning of magnesium is repeated several times with different weights of magnesium, it will be found that a definite weight of magnesium combines* with a definite weight of oxygen to form magnesium oxide. Thus 12 grams of magnesium combines with 8 grams of oxygen to form 20 grams of magnesium oxide, and 24 grams of magnesium combines with 16 grams of oxygen to form 40 grams of magnesium oxide. The ratio of magnesium to oxygen is 24 to 16 or 3 to 2 or 60 per cent. magnesium to 40 per cent. oxygen. Thus we have the Law of Definite Proportions, which states that the ratio by weight in which elements combine chemically to form a definite chemical compound is always the same.

LAW OF MULTIPLE PROPORTIONS

If we consider the oxidation of carbon, under certain conditions one type of oxide is formed and under other conditions another type of oxide is formed. In the one case 12 grams of

carbon combine with 16 grams of oxygen to form 28 grams of carbon monoxide, whereas in the other case 12 grams of carbon combine with 32 grams of oxygen to form 44 grams of carbon dioxide. The ratio by weight in which the oxygen combines with the same weight of carbon is 2 to 1. This leads to the Law of Multiple Proportions, which states that if an element combines with another element to form more than one chemical compound the weights of the one which combine with a fixed weight of the other bear a simple relation to one another.

MIXTURES

Sulphur and iron filings form a mixture which can be separated by mechanical means. Thus if a magnet be placed in a mixture of sulphur and iron filings, the filings are attracted by the magnet and the sulphur is left behind. The percentage composition of the mixture may vary according to the quantities of sulphur and iron present.

If, however, a mixture of sulphur and iron filings be heated strongly a definite compound is produced, in which the percentage composition is always the same. If the sulphur or the iron is in excess one of them remains unchanged at the end of the process.

OXYGEN

Preparation

Fig. 146 shows an ignition tube A, fitted with a cork and delivery tube B and containing a mixture of potassium chlorate and manganese dioxide in the proportion of 9 to 1 by weight. An inverted gas jar C, filled with water, stands on a beehive shelf D, in a trough containing water. A piece of iron gauze is wrapped round the tube and when the tube is heated strongly by a bunsen burner, oxygen is driven off. If the oxygen is allowed to escape for a time so as to displace all the air from the apparatus, a few jars of the gas can be collected by the downward displacement of water. Then the delivery tube should be disconnected from the ignition tube so as to prevent water from being drawn into the apparatus as it cools.

The manganese dioxide is unchanged at the end of the experiment. It is known as a catalyst and merely improves the rate at which oxygen is given off.

Properties

Oxygen is a colourless, odourless gas which is only slightly soluble in water. When a glowing splint is introduced into a jar

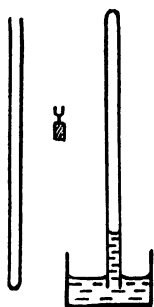


FIG. 144

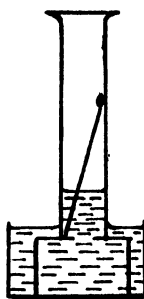


FIG. 145

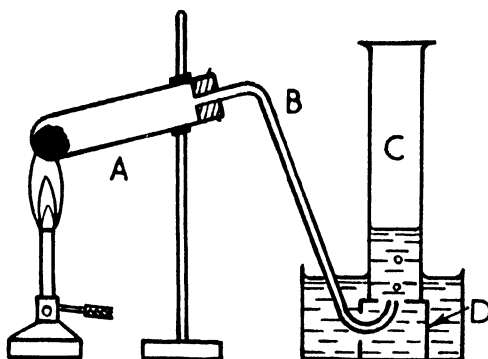


FIG. 146

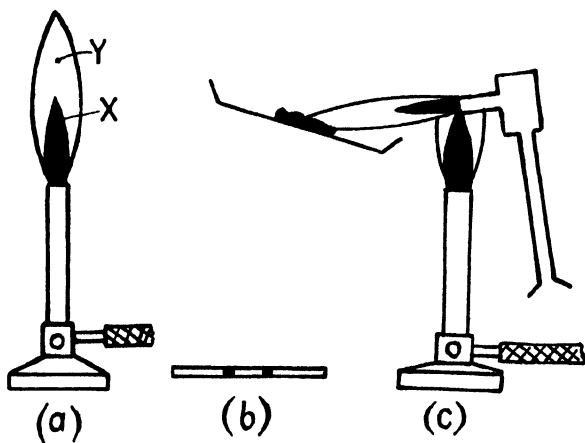


FIG. 147

containing oxygen, the splint bursts into flame. A piece of magnesium burns in air with a white flame, but when introduced into a jar containing oxygen, the flame is far more intense. A piece of glowing charcoal introduced into a jar containing oxygen bursts into flame. Thus we see that oxygen supports burning to a greater extent than air, but it does not burn. Elements which burn in oxygen are said to oxidise and form oxides.

Physiological Properties of Oxygen

Oxygen is the essential constituent of air for the purpose of supporting life. Hence it is necessary in mining practice to observe certain standards.

The Coal Mines Act, 1911, states that the oxygen content of the air in a working place, with certain exceptions, shall not be less than 19 per cent. by volume. Observations have been made relating to the deficiency of oxygen in the atmosphere and the corresponding increase of carbon dioxide which occurs in a limited atmosphere in which combustion or respiration has been taking place for some time. The results show that 16 per cent. of oxygen in the atmosphere produces excessive panting which results in severe distress. If only 11 per cent. of oxygen is present in the atmosphere the effect is to cause collapse and ultimately death.

THE BUNSEN FLAME

When a bunsen burner is lit with the holes at the bottom open, air is drawn through the holes and the flame is nearly invisible. When the holes are partly open, the flame becomes more luminous.

A bunsen flame consists of two distinct portions, an inner cone X which consists of unburnt gas (hydrocarbons, hydrogen, etc.) and an outer envelope Y in which the gas is burning, i.e. combining with the oxygen of the air. The outer envelope, which is at a very high temperature, is known as the oxidising flame, and certain metals when placed in it are oxidised. The inner cone is relatively colder (Fig. 147a).

The structure of the flame can be shown by holding a match horizontally over the flame at a point just underneath the top of the inner zone. The effect is shown in Fig. 147b.

Metals can be oxidised by using a blowpipe such as the one shown in Fig. 147c. The metal is placed in a porcelain lid and the blowpipe directs the bunsen flame upon it, so that the tip

of the outer zone is in contact with the metal. The blast of air increases the supply of oxygen available for the oxidation.

NITROGEN

When all the oxygen in a jar containing air is used up by the burning of a substance such as phosphorus or by absorption with alkaline pyrogallol, the remaining gas is mainly nitrogen.

Nitrogen can be prepared by passing air over heated copper turnings (Fig. 148). When water is allowed to run out of the vessel A into the bottle B, air is driven through the hard glass tube C which contains copper turnings heated to a high temperature. The copper, in forming black copper oxide, removes the oxygen from the air and the residual gas nitrogen is collected over water in the jar D.

If a lighted taper is placed in a jar containing nitrogen, the flame is extinguished immediately, showing that nitrogen does not support combustion. Nitrogen does not support respiration or breathing, for human beings or animals in a confined space are suffocated when a considerable proportion of the oxygen is used up. Nitrogen is not poisonous. In air it simply acts as a diluent for the oxygen.

CARBON DIOXIDE

The apparatus shown in Fig. 149 consists mainly of an aspirator A and a Wolff's bottle B containing lime water. All the joints are airtight. Water is allowed to flow from the aspirator and in this manner air is drawn through the lime water, which becomes milky in appearance. If the bottle C which contains caustic soda solution is attached to the bottle B by means of a piece of rubber tubing and fresh lime water is placed in B, when water is again allowed to flow out of the aspirator, the lime water is unaffected. Evidently in the first case there is some gas in the air which turns lime water milky and in the second case this gas is removed by the caustic soda solution. This constituent of the air is called carbon dioxide.

If air is drawn through the caustic soda solution as before it will be found that the lime water in B is unaffected. But on disconnecting the bottle B from the other apparatus, introducing a lighted splint into the bottle and shaking, the lime water turns milky.

Evidently the burning of the wood produces carbon dioxide. In fact the burning of all materials which contain carbon produces this gas.

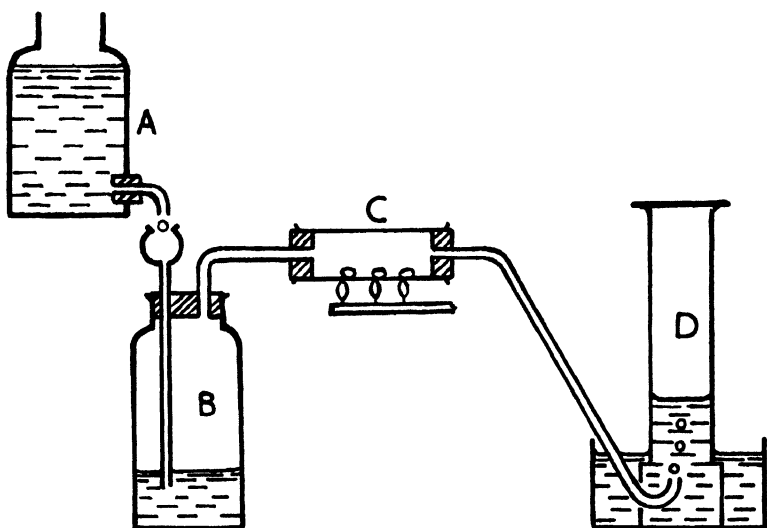


FIG. 148

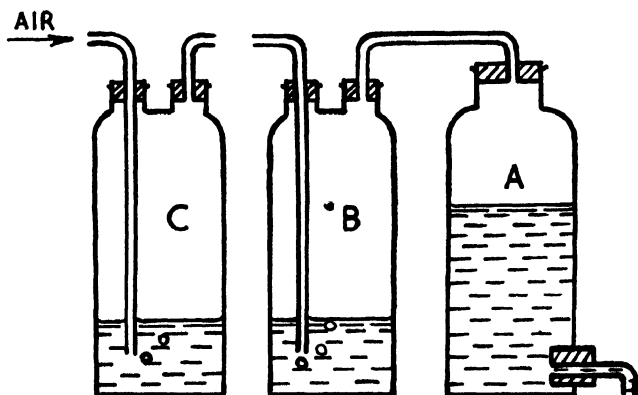
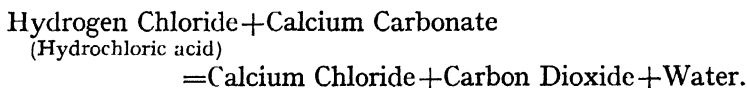


FIG. 149

Preparation of Carbon Dioxide

Fig. 150 shows an apparatus used for generating carbon dioxide. The bottle A is fitted with a stopper through which pass the thistle funnel B and the delivery tube C. The bottle contains marble chips, a form of calcium carbonate. If dilute hydrochloric acid is poured down the funnel, the acid acts upon the marble, producing effervescence. Carbon dioxide gas is evolved and is collected by the upward displacement of air in the jar. The chemical reaction can be represented thus:



Properties of Carbon Dioxide Gas

Carbon dioxide is an odourless, colourless gas which as we have seen turns lime water milky. This property is a test for the gas. Carbon dioxide is much heavier than air, which can be shown by pouring the gas from one jar to another in the same way as the pouring of water. When the lower jar, to which lime water has been added, is shaken the lime water assumes a milky appearance.

Another way of showing that carbon dioxide gas is heavier than air is to counterpoise a beaker on a balance and to pour carbon dioxide into it from a gas jar (Fig. 151). The carbon dioxide displaces the air in the beaker, and the balance shows an increase in weight.

The greater density of carbon dioxide compared with air is very important from the point of view of the miner. Carbon dioxide (a constituent of blackdamp), being heavier than air, collects near the floor of the workings and may form an extinctive atmosphere (see p. 229).

In ordinary air carbon dioxide is produced by the burning of substances containing carbon, e.g. wood, coal, etc. The percentage quantity of carbon dioxide in ordinary air remains practically fixed, viz. 0.06 per cent. by weight. This seems strange at first sight, as we should expect the air in industrial districts near mills, mines, etc., to contain a much larger percentage of the gas. Nevertheless, on the whole, the percentage remains about the same. The reason for this will now be discussed.

When carbon dioxide is bubbled into water contained in a trough, some of the gas escapes but a large quantity dissolves

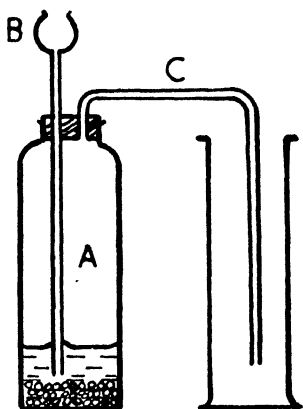


FIG. 150

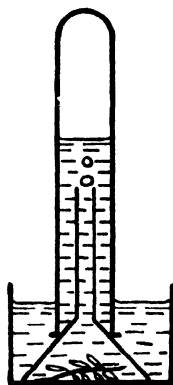


FIG. 152

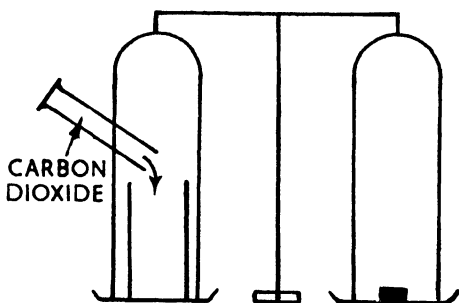


FIG. 151

in the water. If a green plant is placed in the trough underneath a funnel (Fig. 152) and a test tube filled with water is supported over the funnel, after allowing the apparatus to stand in sunlight for a few weeks, a gas collects in the test tube, and when this gas is tested with a glowing splint it is found to be oxygen.

Respiration

It has already been seen that the burning of wood, etc., produces carbon dioxide. This gas is also produced in the process of breathing. Animals and human beings breathe in air and some of the oxygen is converted into carbon dioxide in the lungs. Thus the air breathed out contains a larger percentage of carbon dioxide. Plants also breathe in air and convert some of the oxygen into carbon dioxide, but in sunlight green plants carry on a process known as photo-synthesis or light building, in which they convert carbon dioxide into oxygen. As far as plant life is concerned the total effect of the two processes results in plants absorbing carbon dioxide and converting it into oxygen. Thus a balance exists whereby the percentage of carbon dioxide in the atmosphere remains the same.

The Air as a Mixture

We have seen that air consists mainly of oxygen and nitrogen in the proportion of 1 to 4 by volume. Now air is soluble in water, but the oxygen dissolves more readily than the nitrogen. Thus air driven off from water by heating contains a larger ratio of oxygen to nitrogen. This could not be so if the gases were in chemical combination. We conclude therefore that air is a mixture.

OCCURRENCE OF CARBON DIOXIDE IN MINES

Small quantities of carbon dioxide are produced in mine workings by breathing, by the burning of lamps and also from the use of explosives. Larger quantities of carbon dioxide are due to the oxidation of coal and other carbonaceous substances and the action of acidic waters on limestone in the strata (see p. 192). Large quantities of carbon dioxide are also found after an explosion. This is commonly known as choke damp.

Practical Uses of Carbon Dioxide

Carbon dioxide is a constituent of carbogen which is used in modern reviving apparatus. Carbogen consists of a mixture of carbon dioxide and oxygen in definite proportions. These proportions are fixed by C.M.A. regulations appertaining to rescue appliances and are such that the percentage of carbon dioxide in the mixture shall not be less than 5 per cent. or greater than 7 per cent. The use of carbon dioxide in the mixture utilises the physiological effect of this gas, which is to increase the depth of breathing. This property together with the high percentage of oxygen present is of valuable use when applied

to a person rendered unconscious by noxious gases such as firedamp, blackdamp, etc.

A cylinder containing carbon dioxide under pressure constitutes a modern type of fire extinguisher in use at collieries. These extinguishers may be used with particular advantage in combating fires in electrical appliances.

WATER VAPOUR

We have already seen (Ch. VIII) that water vapour is a very important gas as far as mining practice is concerned. Water vapour is produced in ordinary air by evaporation from sheets of water and, since currents of air from the outside atmosphere pass down the downcast shaft, water vapour is also present in mine air. Perspiration from the miner's body and evaporation of water from sump holes also increase the quantity of water vapour in mine air.

EXERCISES

1. How would you prepare oxygen in the laboratory? Give an account of the properties of oxygen which are of particular interest from the point of view of the miner. (Min. Sc.; U.L.C.I.)

2. How would you show that the atmosphere is a mixture of gases? How does exhaled air differ from normal air? What impurities are likely to be present in mine air? (Min. Sc.; U.L.C.I.)

3. Describe the preparation of carbon dioxide, giving a sketch of the apparatus used. Give an account of the occurrence of this gas in coal mines and its effects on animal life. How may the amount of carbon dioxide in a sample of mine air be determined? (Min. Sc.; U.L.C.I.)

4. How would you prepare a sample of oxygen in the laboratory? What are the chief properties of oxygen and what is the minimum percentage required for safety in mines? (Min. Sc.; U.E.I.)

5. A candle is lighted and placed in a wide-mouthed glass jar. The mouth of the jar is then covered with a piece of cardboard. What do you expect to observe, and why? (Min. Sc.; U.L.C.I.)

6. Explain carefully how you would prepare oxygen, and the experiments you would perform to show its properties. State and explain what happens in each experiment. (Min. Sc.; U.L.C.I.)

7. Describe the preparation of oxygen, giving a sketch of the apparatus used. Give a brief account of the properties of this gas, and describe its uses in rescue operations. (Min. Sc.; U.L.C.I.)

CHAPTER XVIII

THE CHEMISTRY OF WATER, HYDROGEN, SULPHUR AND CARBON

COAL—DISTILLATION AND PROXIMATE ANALYSIS

WATER AND ITS CONSTITUENTS

Water is a tasteless, colourless and odourless liquid which under a pressure of 760 mm. of mercury boils at 100° C. and freezes at 0° C.

Water in large quantities can easily be detected, but when in small quantities it may be difficult to distinguish it from other colourless liquids without some reliable test. White anhydrous copper sulphate is an infallible test for water, for the colour of this substance becomes blue in the presence of small traces of water.

SOLUTIONS

If one or two potassium permanganate crystals are shaken up with water in a flask, the water assumes a pinkish colour. If more water is added, the permanganate spreads out over the whole of the water and the colour becomes less pink. The potassium permanganate is said to dissolve in the water to form a solution, the permanganate being the solute and the water the solvent. When more water is added the solution is said to be diluted, and theoretically there is no limit to the amount of dilution a solution may undergo.

When common salt is dissolved in water, a colourless solution is produced. If more salt is added more dissolves and the solution is said to become stronger. When more and more salt is added, a stage is reached when no more salt will dissolve in the given quantity of water. There is excess of salt left at the bottom of the vessel and the solution is said to be saturated at the particular temperature.

In the case of common salt (sodium chloride), heating the solution and shaking the vessel causes more salt to dissolve and the solution becomes saturated at a higher temperature.

Solubility

The solubility of a solid in a solvent is measured by the weight of the solid in grams which can be dissolved in 100 grams of the solvent at the given temperature.

The following table gives the solubility of common salt and saltpetre in water at various temperatures.

Substance	0° C.	50° C.	100° C.
Common salt .	35.5	37	39.6
Saltpetre . .	13.3	86	246

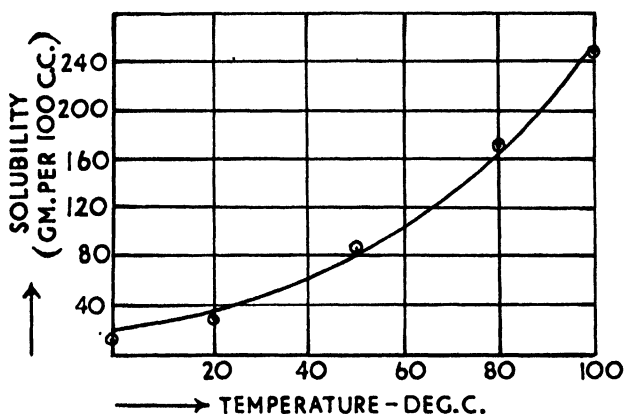


FIG. 153

The graph (Fig. 153) shows the solubility of saltpetre at different temperatures.

In the case of some salts, however, increase of temperature does not cause more salt to dissolve in the water. In fact some salts are more soluble in cold than in hot water.

When a solution of a non-volatile salt (i.e. one which does not vaporise) is boiled, water is driven off in the form of steam and if the boiling is continued until all the water disappears, the solid is left behind in the vessel. Thus in the case of a solution of sodium chloride, a white powder is left in the evaporating dish. Also a solution of blue copper sulphate when evaporated to dryness leaves a white powder known as anhydrous copper sulphate.

Water of Crystallisation

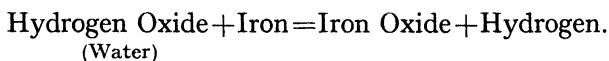
When a hot saturated solution of copper sulphate is rapidly cooled, crystals of a blue colour separate out. When these crystals are examined under a microscope, they are found to have a definite shape with flat regular faces. A small crystal of copper sulphate placed in saturated copper sulphate solution grows into a large crystal of the same shape.

Crystals of copper sulphate, alum, etc., all contain water, yet appear quite dry to the touch. When copper sulphate crystals are heated in a test tube, the water is driven off as steam, which condenses on the colder portions of the tube. A white powder is left which, as we have seen, is anhydrous copper sulphate. If a little water is added the salt turns blue and crystals again form. The water is in chemical combination with the salt and is known as water of crystallisation.

ANALYSIS OF WATER BY PASSING STEAM OVER RED-HOT IRON

Fig. 154 shows a flask A, fitted with a rubber stopper through which pass the delivery tube B and the safety tube C. The flask is supported in an iron stand and rests on a piece of gauze fixed to a tripod. The delivery tube B is connected to an iron tube D which contains a quantity of iron nails and rests in a furnace. The tube E leads from the tube D to the inverted gas jar F. This jar is filled with water and rests on a beehive shelf in a trough G, containing water.

When steam is generated it passes over the red-hot iron and the gas evolved together with the air in the apparatus is allowed to escape for a time. Then the gas is collected by the downward displacement of water. This gas is hydrogen and the reaction is shown below:



If a lighted taper is applied to the mouth of a jar containing the gas, the gas burns with a blue flame.

HYDROGEN

Preparation

If dilute sulphuric acid is poured down the thistle funnel A (Fig. 155) upon granulated zinc in the bottle B, effervescence takes place. The gas hydrogen is evolved and is collected in the

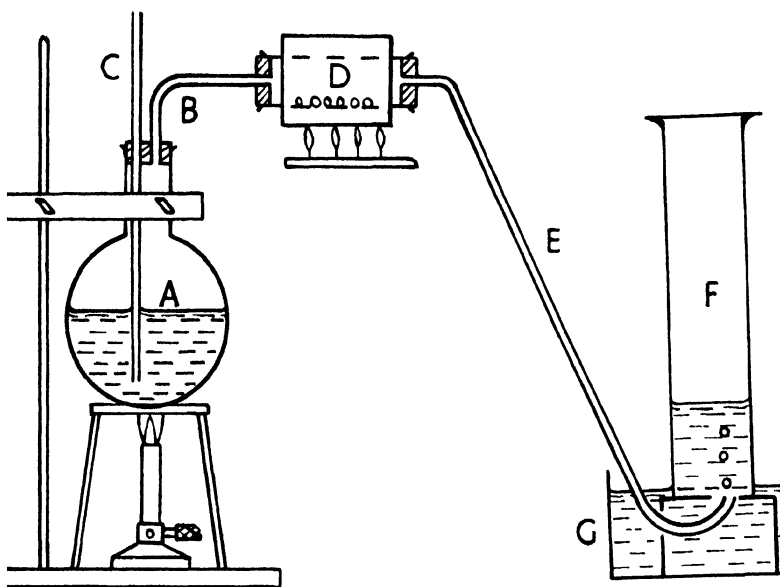


FIG. 154

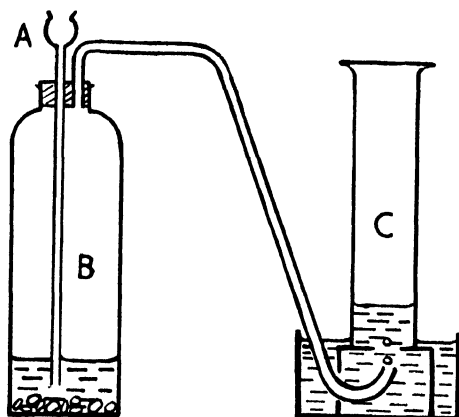
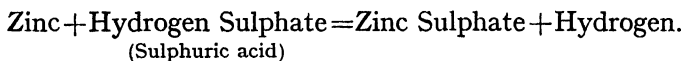


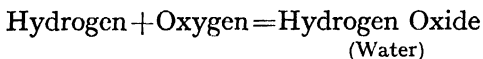
FIG. 155

jar C by the downward displacement of water. The chemical reaction is shown below:



Properties

Hydrogen is a colourless, odourless and tasteless gas. If a lighted taper is introduced into a jar containing hydrogen, the flame is extinguished, but the gas burns with a blue flame. This shows that although hydrogen burns it will not support burning. The burning of hydrogen is represented as below:



Hydrogen can be burned at a jet in the same way as coal gas. Fig. 156 shows a jet of burning hydrogen impinging on a flask through which cold water is circulating. If a watch-glass is placed directly underneath the jet, a colourless liquid collects in the glass. When this liquid is examined with anhydrous copper sulphate it is found to be water.

If a mixture of hydrogen and oxygen in the ratio of 2 to 1 by volume is ignited, an explosion takes place and the product of combustion is the minute volume of water formed.

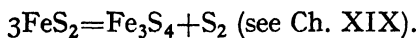
Hydrogen is much lighter than air; in fact hydrogen is the lightest gas known. If the tube A (Fig. 157) is filled with hydrogen and the tube B with air, after a time the air in B is displaced by the hydrogen from the tube A. If a lighted match is placed near the mouth of the tube B, there is a slight explosion, showing that hydrogen has ascended into the upper vessel.

SULPHUR

Sulphur occurs in nature combined chiefly with the metals zinc, mercury, iron and lead, forming zinc sulphide (zinc blende), mercury sulphide (cinnabar), iron disulphide (iron pyrites) and lead sulphide (galena) respectively.

When iron disulphide (iron pyrites) is heated in a hard glass tube a gas is given off. This gas condenses on the colder portions of the tube as a yellow powder and in the hotter portions as a yellow or brown liquid. On further cooling, the contents of the tube assume a yellow solid state.

The decomposition of the pyrites is represented thus:



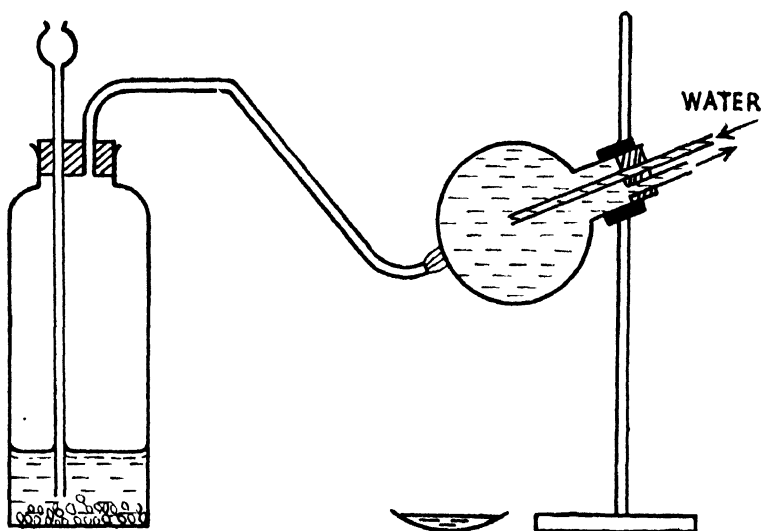


FIG. 156

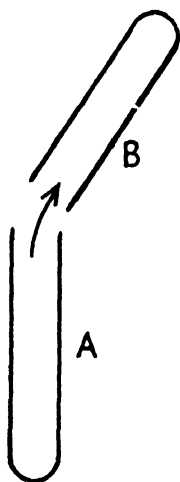


FIG. 157

Properties of Sulphur

Sulphur is a yellow brittle substance which melts at $114.5^{\circ}\text{C}.$, forming a pale yellow liquid. When heated to a temperature between $200^{\circ}\text{C}.$ and $250^{\circ}\text{C}.$ sulphur becomes darker in colour and extremely viscid. On further heating to its boiling point, viz. $445^{\circ}\text{C}.$, sulphur changes into a brownish-yellow vapour. When sulphur is heated in oxygen to a sufficiently high temperature, sulphur dioxide gas is produced. In combination with carbon, sulphur forms carbon disulphide, and in combination with hydrogen it forms hydrogen sulphide gas (sulphuretted hydrogen).

FORMS OF SULPHUR

Crystals of Sulphur

When molten sulphur solidifies, the particles arrange themselves in regular forms called crystals which have the appearance of yellow needles. In the case of the deposition of sulphur from a solution, the crystals are in the form of octahedrons with rhombic bases.

Flowers of Sulphur

Sulphur may also be obtained in the amorphous or uncrystallised form. When sulphur is heated to boiling point, it vaporises and becomes a brownish-yellow gas which on condensing forms a yellow powder in the colder portions of the tube. This powder is known as flowers of sulphur.

Plastic Sulphur

Sulphur near its boiling point when poured into cold water forms a soft, yellow, translucent mass of plastic sulphur.

CARBON

Carbon is a constituent of all plants and animals and may be prepared in the laboratory by heating sawdust, flour, sugar, coal, etc., to a high temperature, in iron spoons, in a limited supply of air. On a large scale, in the manufacture of coal gas, coal is heated in a limited supply of air, in iron or fireclay retorts. The gaseous products of the distillation pass through an opening in the retort and coke, a form of carbon, is left at the bottom.

Animal charcoal, which is another form of carbon, is the residue produced when bones are heated strongly out of contact with air. When animal charcoal is heated strongly in air, the carbon burns away and a white ash is left.

Charcoal is produced by the burning of stacks of wood, covered with turf so as to limit the supply of air. Part of the wood burns and the heat produced chars the remainder.

Soot or lampblack is a form of carbon which is produced by the burning of substances rich in carbon when the air is in short supply.

Graphite is a crystalline form of carbon which is produced by dissolving charcoal in molten cast iron. On cooling the carbon separates into a crystalline form and the iron can be removed by dissolving it in acid.

Carbon is a very inert substance at ordinary temperatures, while at high temperatures it combines with oxygen, forming either carbon monoxide or carbon dioxide. Carbon is also a constituent of carbon disulphide and the various hydrocarbons such as ethylene, acetylene, methane, etc. Since carbon has the property of withdrawing oxygen from metallic oxides, it is a good reducing agent (see p. 210).

COAL—ITS ORIGIN AND FORMATION

The decay of vegetation of bygone ages, and the compression of this vegetation by overlying strata of earth, has resulted in the formation of coal. The type of coal depends to a great extent on the nature of the vegetation and the amount of decay which has taken place. Since coal is formed from wood whose principal constituents are cellulose, resins, proteins and sap juices it is quite obvious that it contains practically all the substances produced by the decay of these constituents. A small amount of mineral matter, known as ash, is also a constituent of coal.

The following table gives the approximate percentages by weight of the various elements present in bituminous coal and anthracite.

Type of Coal	Carbon	Hydrogen	Oxygen	Nitrogen
Bituminous coal . .	83%	5%	10%	1.0%
Anthracite	93%	3%	3%	0.7%

Destructive Distillation of Coal

Coal gas, which is produced by the destructive distillation of coal, consists of combustible gases many of which are highly luminous. These gaseous substances include ethylene,

the olefines, acetylene, hydrogen and carbon monoxide. Very important by-products are formed in the distillation of coal. These include coal tar, hydrogen sulphide, carbon disulphide, ammoniacal liquor, benzol and naphthalene.

PROXIMATE ANALYSIS OF COAL

For commercial purposes proximate analysis of coal samples is of considerable importance. The main essentials are (a) contained moisture, (b) volatile content and (c) ash content.

The percentage of moisture is an important consideration,

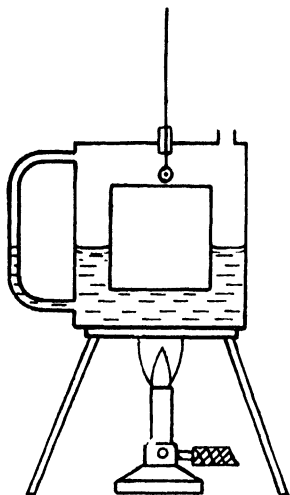


FIG. 158

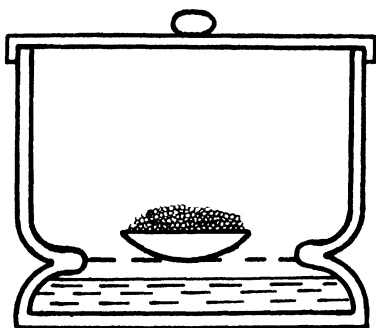


FIG. 159

since the consumer has to pay for it if the contract involves payment by weight of coal purchased. In the case of the volatile content this will depend on the consumer's object. The volatiles consist of gases and the vapours of liquids from which, after purification, coal tar, ammonia, toluene, benzene, naphthalene and other by-products are obtained. Hence the above-mentioned by-products may be of considerable importance to consumers. The calorific value of some of the gases and the hydrocarbons is of course very important in steam-raising plants.

Finally the ash content of the coal is of importance, since the higher the percentage of mineral matter in the coal then the higher is the overall cost to the consumer. In addition there is the expense of the removal of the ashes after combustion.

Determination of the Moisture Content of a Sample of Coal

The determination of the moisture content of a coal sample is carried out in the following manner. Two watch-glasses are weighed together. Then a small amount of the sample which has been ground to such a size that it will pass through a 90-mesh sieve, is placed on one of the watch-glasses, the other being used as a cover. The watch-glass containing the sample is weighed, together with the cover glass. The cover glass is removed and the watch-glass and sample are placed in a water oven (Fig. 158) at a temperature of 100°C . The sample is heated in this manner for one hour, after which the watch-glass and sample are cooled in a desiccator (Fig. 159). The desiccator consists of a glass vessel with two compartments, one above the other and separated by gauze, the lower compartment containing strong sulphuric acid or calcium chloride, both of which absorb water. The watch-glass, sample and cover are reweighed, then reheated as before for 15 minutes and, after cooling, weighed again. This process is continued until there is no change in weight, and from the data collected the moisture content is calculated.

The experiment is repeated with a further sample of coal and a mean value for the moisture content is found. A set of results is shown below.

$$\begin{aligned}
 (1) \quad & \text{Weight of two watch-glasses} && = 17.51 \text{ gm.} \\
 & \text{Weight of two watch-glasses} + \text{coal} && = 22.51 \text{ gm.} \\
 \therefore & \text{Weight of coal} && = 5 \text{ gm.} \\
 & \text{Weight of two watch-glasses} + \text{coal} && = 22.35 \text{ gm.} \\
 & \quad \text{(after 1 hour in oven)} \\
 & \text{Weight of two watch-glasses} + \text{coal} && = 22.28 \text{ gm.} \\
 & \quad \text{(after further 15 minutes)} \\
 & \text{Weight of two watch-glasses} + \text{coal} && = 22.28 \text{ gm.} \\
 & \quad \text{(after further 15 minutes)} \\
 \therefore & \text{Weight of moisture in sample} && = 22.51 \text{ gm.} \\
 & && \quad \quad \quad - 22.28 \text{ gm.} \\
 & && = 0.23 \text{ gm.} \\
 \text{Hence percentage of moisture in sample} &= \frac{0.23}{5} \times 100 \\
 &= 4.6 \text{ per cent.}
 \end{aligned}$$

$$\begin{aligned}\therefore \text{Loss in weight due to volatiles and} &= 12.734 \text{ gm.} \\ \text{moisture} &\quad - 12.350 \text{ gm.} \\ &= 0.384 \text{ gm.}\end{aligned}$$

$$\begin{aligned}\text{But the weight of moisture in} &= \frac{4.7}{100} \text{ gm.} \\ \text{1 gm. of coal} &= 0.047 \text{ gm.}\end{aligned}$$

$$\begin{aligned}\therefore \text{Weight of volatiles in 1 gm. of coal} &= 0.384 \text{ gm.} \\ &\quad - 0.047 \text{ gm.} \\ &= 0.337 \text{ gm.}\end{aligned}$$

$$\therefore \text{Percentage of volatile matter in sample} = 33.7 \text{ per cent.}$$

$$\begin{aligned}(2) \quad \text{Weight of crucible and lid} &= 11.732 \text{ gm.} \\ \text{Weight of crucible, lid and coal} &= 12.732 \text{ gm.} \\ \text{Weight of crucible, lid and coke} &= 12.348 \text{ gm.} \\ \therefore \text{Loss in weight due to volatiles} &= 12.732 \text{ gm.} \\ &\quad - 12.348 \text{ gm.} \\ &= 0.384 \text{ gm.}\end{aligned}$$

$$\begin{aligned}\text{But weight of moisture in 1 gm.} & \\ \text{of coal} &= 0.047 \text{ gm.}\end{aligned}$$

$$\begin{aligned}\therefore \text{Weight of volatiles in 1 gm. of coal} &= 0.384 \text{ gm.} \\ &\quad - 0.047 \text{ gm.} \\ &= 0.337 \text{ gm.}\end{aligned}$$

$$\therefore \text{Percentage of volatile matter in coal sample} = 33.7 \text{ per cent.}$$

$$\therefore \text{Mean percentage of volatile matter in coal sample.} = 33.7 \text{ per cent.}$$

Determination of Ash Content of a Coal Sample

A porcelain crucible is weighed empty and then one gram of the powdered sample (90-mesh) is added. The crucible and contents are placed in a furnace and heated gradually for half an hour up to a temperature of 400°C . This heating is continued for a further half-hour until the temperature reaches 700°C . Then the temperature is maintained constant at 700°C . and the heating is continued for a further half-hour.

The crucible and contents are then removed from the furnace and, after cooling in a desiccator, are again weighed. The crucible and contents are then placed in the furnace for 15 minutes

and heated to 700° C. and, after cooling as before, are again weighed. If a change in weight is indicated, this heat treatment is applied until the weight remains constant. Periodic stirring of the sample by means of a platinum wire is carried out throughout the experiment. From the data obtained the ash content may be calculated and a mean value is obtained by carrying out the experiment in duplicate. A set of results is shown below.

(1)	Weight of crucible	=7.71 gm.
	Weight of crucible+coal	=8.71 gm.
	Weight of crucible+ash (after 90 minutes heating)	=7.77 gm.
	Weight of crucible+ash (after a further 15 minutes heating)	=7.77 gm.
\therefore	Weight of ash	=0.06 gm.
\therefore	Percentage ash content of sample	=6 per cent.
(2)	Weight of crucible	=7.43 gm.
	Weight of crucible+coal	=8.43 gm.
	Weight of crucible+ash (after 90 minutes heating)	=7.49 gm.
	Weight of crucible+ash (after a further 15 minutes heating)	=7.49 gm.
\therefore	Weight of ash	=0.06 gm.
\therefore	Percentage ash content of sample	=6 per cent.
\therefore	Mean percentage ash content of sample	=6 per cent.

The three previous determinations form the basis of "Proximate Analysis." Thus we may state the following properties of the coal sample:

Moisture content = 4.7 per cent.

Volatile matter = 33.7 per cent.

Ash content = 6.0 per cent.

Total = 44.4 per cent.

The percentage of fixed carbon may be obtained by subtracting the above total from 100 per cent.

i.e. Fixed carbon in coal sample = $100 - 44.4$
= 55.6 per cent.

EXERCISES

1. Describe the chief properties of carbon. What are the chief elements, besides carbon, normally present in coal? (Min. Sc.; U.L.C.I.)
2. How is sulphur commonly obtained? Give an account of the action of heat on sulphur.
3. Describe the methods of obtaining the crystalline forms of sulphur.
4. Describe a method for the proximate analysis of coal.
(Min. Sc.; U.L.C.I.)
5. Describe one of the following:
 - (a) The proximate analysis of coal.
 - (b) The analysis of mine air, which may contain carbon dioxide and methane.
(Min. Sc.; U.L.C.I.) (See Ch. XX.)

CHAPTER XIX

CHEMICAL THEORY, ACIDS, BASES AND ALKALIS, HARD AND SOFT WATERS

REDUCTION

A reducing agent is a substance which withdraws oxygen from another substance in the course of a chemical change. Important reducing agents are hydrogen, carbon monoxide and coal gas which contains a quantity of hydrogen.

Fig. 160 shows an apparatus in which A is a hard glass tube,

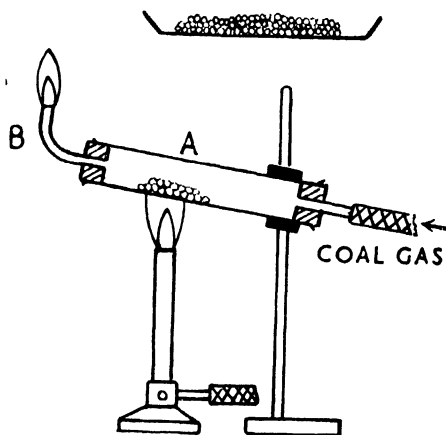


FIG. 160

containing a quantity of black copper oxide and through which coal gas is passed. If the coal gas is lit at the jet B, so as to prevent its escape into the atmosphere, and the tube is strongly heated, the copper oxide is completely reduced to metallic copper.

If the experiment is repeated with a known weight of copper oxide in a porcelain boat and coal gas is again passed through the heated tube, after allowing the tube to cool, the porcelain boat shows a loss in weight. If on repeating the experiment there is no further loss in weight, the reduction is complete.

A set of results is shown below.

	Weight of dish + copper oxide	= 5.75 gm.
	Weight of dish	= 4.26 gm.
∴	Weight of copper oxide	= 1.49 gm.
	Weight of dish + copper	= 5.45 gm.
	Weight of dish	= 4.26 gm.
∴	Weight of copper	= 1.19 gm.

Hence 1.49 gm. of copper oxide are reduced to 1.19 gm. of copper,

or 1.19 gm. of copper are in chemical combination with 0.30 gm. of oxygen.

i.e. 1 gm. of copper combines with 0.25 gm. of oxygen.

CHEMICAL EQUIVALENT

Experiments including the above, show that:

4 gm. of copper combine with 1 gm. of oxygen.

1.5 gm. of magnesium combine with 1 gm. of oxygen,

and 0.125 gm. of hydrogen combines with 1 gm. of oxygen.

Thus 4 gm. of copper are equivalent to 0.125 gm. of hydrogen,

or 32 gm. of copper are equivalent to 1 gm. of hydrogen.

Also 1.5 gm. of magnesium are equivalent to 0.125 gm. of hydrogen.

or 12 gm. of magnesium are equivalent to 1 gm. of hydrogen.

In fact, we may conclude that the weights of the various elements which combine with one gram of hydrogen are equivalent to one another.

The chemical equivalent of an element is the number of grams of the element which will combine with or displace 1 gram of hydrogen, 8 grams of oxygen or 35.5 grams of chlorine.

ATOMS AND MOLECULES

An atom is the smallest conceivable part of an element which can enter into a chemical reaction. In some elements the atoms cannot exist alone but are arranged in pairs. Thus two atoms of oxygen always exist together as a molecule of oxygen and two atoms of hydrogen exist together to form a molecule of hydrogen. Such molecules are known as diatomic molecules. In the case of a compound such as water, two atoms

of hydrogen combine with one atom of oxygen to form a tri-atomic molecule.

Whether the substance be element or compound subdivision cannot take place beyond the molecule if the chemical composition of the substance remains unchanged. Thus we may define a molecule as the smallest conceivable part of a substance which is capable of separate existence.

Atomic Weights

The relative weights of atoms can be obtained by finding the proportions in which various elements combine. It has been found that one gram of magnesium combines with $\frac{2}{3}$ gram of oxygen; but since an atom of magnesium combines with an atom of oxygen (see valency, p. 213), one gram of magnesium and $\frac{2}{3}$ gram of oxygen contain the same number of atoms. Thus the weight of an atom of magnesium is $\frac{3}{2}$ times the weight of an atom of oxygen.

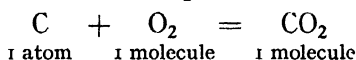
Taking hydrogen as a standard and representing its atomic weight by unity, the atomic weights of other elements are given in the following table. The symbols representing the various elements are also given.

Element	Symbol	Atomic Weight	Element	Symbol	Atomic Weight
Hydrogen . .	H	1	Tin . . .	Sn	118
Oxygen . .	O	16	Zinc . . .	Zn	65
Nitrogen . .	N	14	Lead . . .	Pb	207
Carbon . .	C	12	Mercury . .	Hg	200
Sulphur . .	S	32	Iron . . .	Fe	56
Calcium . .	Ca	40	Copper . .	Cu	63
Sodium . .	Na	23	Magnesium .	Mg	24
Potassium . .	K	39	Chlorine . .	Cl	35.5

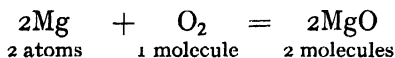
VALENCY

It might be imagined that chemical equivalent and atomic weight are represented by the same number. This is only the case when one atom of an element combines with or displaces one atom of hydrogen. In the case of chlorine, one atom of chlorine combines with one atom of hydrogen and the combining power of chlorine is unity. Thus the formula for hydrochloric acid (hydrogen chloride) is HCl. But in the case of water one atom of oxygen combines with two atoms of hydrogen, the combining power of oxygen is two and the chemical formula for water is H₂O. Again, one atom of carbon combines with four atoms of

The oxidation of carbon is represented as follows:

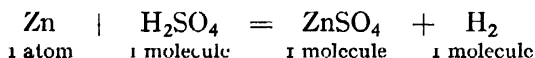


Also the oxidation of magnesium is shown thus.



It should be noted that there is the same number of atoms of each element on each side of the equation.

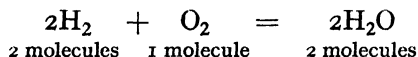
An atom of zinc combines with a molecule of sulphuric acid to form a molecule of zinc sulphate and a molecule of hydrogen, viz.:



AVOGADRO'S LAW

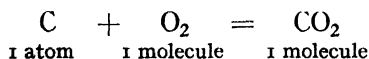
Avogadro's Law states that equal volumes of all gases at the same temperature and pressure contain the same number of molecules.

Suppose there are n molecules in one litre of oxygen and n molecules in a litre of hydrogen. The burning of hydrogen is represented thus:



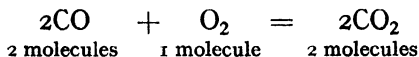
i.e. 2 molecules of hydrogen combine with 1 molecule of oxygen to form 2 molecules of steam. Hence $2n$ molecules of hydrogen combine with n molecules of oxygen to form $2n$ molecules of steam. Therefore 2 litres of hydrogen combine with 1 litre of oxygen to form 2 litres of steam.

Again, suppose there are n molecules in 1 litre of oxygen. The oxidation of carbon to carbon dioxide is shown below:



i.e. 1 atom of carbon combines with 1 molecule of oxygen to form 1 molecule of carbon dioxide. Hence n atoms of carbon combine with n molecules of oxygen to form n molecules of carbon dioxide. Therefore a definite quantity of carbon is oxidised by 1 litre of oxygen to form 1 litre of carbon dioxide.

Again, in the oxidation of carbon monoxide into carbon dioxide, we have:



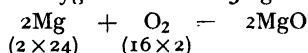
i.e. 2 molecules of carbon monoxide combine with 1 molecule of

oxygen to form 2 molecules of carbon dioxide. Hence $2n$ molecules of carbon monoxide combine with n molecules of oxygen to form $2n$ molecules of carbon dioxide. Therefore 2 litres of carbon monoxide combine with 1 litre of oxygen to form 2 litres of carbon dioxide.

The above considerations lead to the *Law of Gay-Lussac*, which states that *the volumes in which gases combine bear a simple relation to one another and to the volume of the resulting product if that be gaseous*.

CALCULATIONS

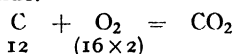
1. Find the weight of oxygen to oxidise 50 grams of magnesium.



Hence 48 gm. of magnesium combine with 32 gm. of oxygen.

$$\therefore \quad 50 \text{ gm. of magnesium combine with } 32 \times \frac{50}{48} \text{ gm. of oxygen} \\ = 33.3 \text{ gm. of oxygen.}$$

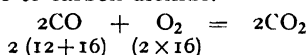
2. Find the weight of oxygen which is required to oxidise 50 gm. of carbon to carbon dioxide.



12 gm. of carbon require 32 gm. of oxygen.

$$\therefore \quad 50 \text{ gm. of carbon require } 32 \times \frac{50}{12} \text{ gm. of oxygen} \\ = 133.3 \text{ gm. of oxygen.}$$

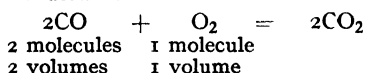
3. Find the weight of oxygen which is required to oxidise 100 gm. of carbon monoxide to carbon dioxide.



56 gm. of carbon monoxide require 32 gm. of oxygen.

$$\therefore \quad 100 \text{ gm. of carbon monoxide require } 32 \times \frac{100}{56} \text{ gm. of oxygen} \\ = 57.1 \text{ gm. of oxygen.}$$

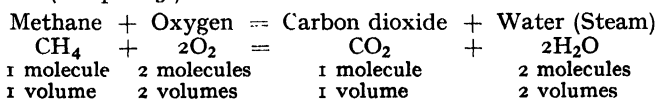
4. What volume of oxygen is required to oxidise 30 cub. ft. of carbon monoxide to carbon dioxide?



i.e. 2 volumes of carbon monoxide require 1 volume of oxygen.

$$\therefore \quad 30 \text{ cub. ft. of carbon monoxide require } \frac{1}{2} \times 30 \text{ cub. ft. of oxygen} \\ = 15 \text{ cub. ft. of oxygen.}$$

5. What volume of oxygen is required to oxidise 10 cub. ft. of methane? (See p. 225.)

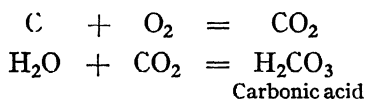


Hence 1 volume of CH_4 requires 2 volumes of oxygen.

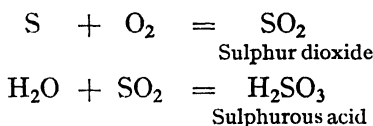
$$\therefore \quad 10 \text{ cub. ft. of } \text{CH}_4 \text{ require } 20 \text{ cub. ft. of oxygen.}$$

ACID-FORMING OXIDES

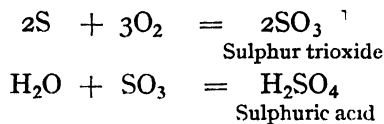
If a piece of glowing carbon is placed in a gas-jar containing oxygen, the carbon burns more brightly and carbon dioxide gas is produced. When a quantity of water is added and the jar is shaken with a lid over the top, the carbon dioxide dissolves in the water. If a little blue litmus solution is added the litmus is turned red. Now the turning of blue litmus red indicates the presence of an acid and evidently when carbon dioxide is dissolved in water an acid is formed. This acid is known as carbonic acid and the chemical reactions which take place in its formation are shown below:



If the above process is repeated by burning sulphur in a jar of oxygen, sulphur dioxide gas is produced. When the products of combustion are shaken up with water and a little blue litmus solution is added the blue litmus is turned red. An acid is thus produced in this case also, and the acid is known as sulphurous acid. The chemical reactions are shown below:



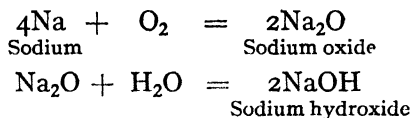
Under certain conditions when sulphur is burned in oxygen sulphur trioxide is produced, and when dissolved in water an acid known as sulphuric acid is produced. The chemical reactions are shown below:



BASES AND ALKALIS

When a little sodium is placed in an evaporating dish and the sodium is ignited, an oxide known as sodium oxide is formed. When a little water is added and the contents of the dish are stirred with a glass rod, sodium hydroxide solution is produced. When a little red litmus solution is added, the litmus turns blue. The turning of red litmus blue indicates the presence of an alkali and evidently sodium hydroxide solution, or

caustic soda solution as it is commonly called, is an alkali. The chemical reactions are shown below:

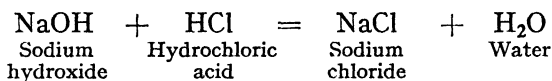


Similarly calcium oxide (lime) and potassium oxide when dissolved in water produce calcium hydroxide (lime water) and potassium hydroxide (caustic potash) respectively. Both calcium and potassium hydroxides turn red litmus solution blue and are therefore alkalis.

Metallic oxides are generally known as bases and bases which dissolve in water form alkalis.

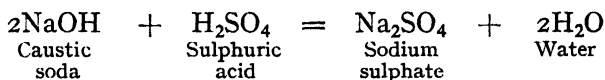
SALT FORMATION

If an evaporating dish contains a quantity of dilute hydrochloric acid, coloured with a little red litmus solution, and caustic soda solution is run into the dish, drop by drop, eventually the red litmus begins to turn blue. The acid is just neutralised by the alkali (caustic soda solution), and if the solution is evaporated to dryness a salt known as sodium chloride (common salt) is left. The chemical reaction is shown below:



The salt remaining is neutral and has no effect on either red or blue litmus.

Another salt known as sodium sulphate can be prepared in a similar manner. If an evaporating dish contains a quantity of caustic soda solution together with a little blue litmus and dilute sulphuric acid is run into the dish, drop by drop, the litmus eventually turns red. Evidently the acid neutralises the alkali and the extra drop of acid turns the blue litmus red. The equation of the reaction is shown below:



If the solution is evaporated to dryness a solid, namely sodium sulphate, is left.

If a little dilute sulphuric acid is poured upon a quantity of black copper oxide in an evaporating dish, a chemical reaction takes place and a blue solution is produced. If the solution is

heated strongly and all the water is driven off, a white powder is left. This powder is the salt known as anhydrous copper sulphate.

The previous experiments show generally that :

Non-metallic oxide + Water = Acid.

Metal + Oxygen = Base.

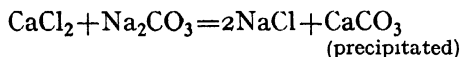
Also : Base + Acid = Salt + Water.

Alkali + Acid = Salt + Water.

Hydrochloric, sulphuric, carbonic and nitric acids when neutralised by an alkali or a base give salts known as chlorides, sulphates, carbonates, and nitrates respectively.

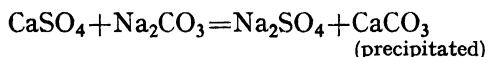
Precipitation

As we have seen, some salts are soluble in water and others are insoluble. In a chemical reaction in which an insoluble salt is produced, this salt is deposited or precipitated. Thus both calcium chloride and sodium carbonate are soluble in water but when the solutions of the two salts are mixed the following reaction takes place:



Sodium chloride and calcium carbonate are produced. The sodium chloride remains in solution, whereas the calcium carbonate, being insoluble in water, is precipitated.

Solutions of calcium sulphate and sodium carbonate mixed together give a precipitate of calcium carbonate according to the following reaction:



The precipitate in each case can be washed and dried and this is a method of preparing a sample of the substance.

IMPURITIES IN WATER

In connection with steam-raising plants at collieries a sufficient supply of water must be available. This water may be obtained from a nearby stream or river or a natural underground supply, and the presence of impurities may be such that the water requires treatment before use.

If the water carries mineral matter in suspension it may be clarified by passing the water through filters before use or by allowing it to stand in settling tanks or ponds.

The treatment of impurities which have a soluble nature is more complex. Samples of the water must be taken and analysed and the impurities, if any, noted. Then the required treatment may be applied.

Soluble impurities may have deleterious effects on the plant, the two most important being a corrosive effect and formation of scale, and impurities may have either or both of these properties. The most common soluble impurities which require treatment are certain salts of calcium, iron and magnesium.

Soluble Impurities forming Scale

The following salts are the most common: calcium bicarbonate ($\text{CaH}_2(\text{CO}_3)_2$), calcium sulphate (CaSO_4), ferrous sulphate (FeSO_4), iron oxide (hydrated), magnesium carbonate (MgCO_3) and magnesium bicarbonate ($\text{MgH}_2(\text{CO}_3)_2$).

Soluble Impurities having a Corrosive Effect

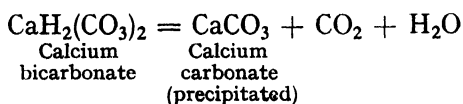
Impurities which produce a marked corrosive effect are ferrous sulphate and magnesium chloride (MgCl_2).

TREATMENT OF BOILER FEED WATERS

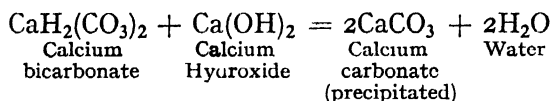
Soluble mineral impurities form "hard" waters and such "hardness" may have two distinct forms, (a) temporary and (b) permanent hardness. Temporary hardness may be removed by boiling the water, whilst permanent hardness requires chemical treatment. Distilled water is often used in high-pressure steam plants and is the most suitable type of feed water which can be used. The water is provided by using a low-pressure boiler in the plant.

Temporary Hardness

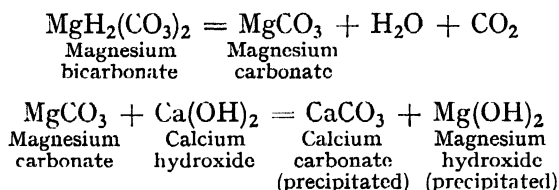
Temporary hardness is caused mainly by the bicarbonates of calcium and magnesium. In the case of calcium bicarbonate, if the water is boiled calcium carbonate is precipitated since it is insoluble in water, and in this manner the hardness is removed. The sediment formed may be removed from the boiler by "blowing-down." The chemical reaction is shown below:



Calcium bicarbonate may also be removed by the addition of lime (calcium hydroxide) according to the following reaction:



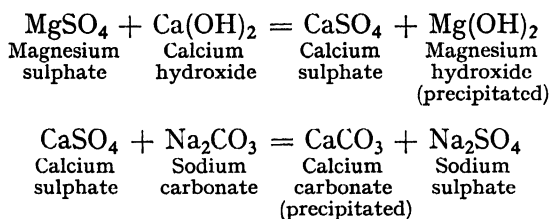
In the case of magnesium bicarbonate in feed water the boiling reduces it to magnesium carbonate, which, however, is soluble. Magnesium carbonate is also a scale-former, so lime must still be added either initially or after boiling:



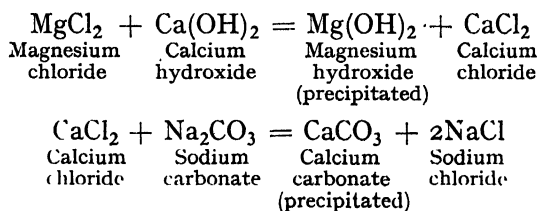
Permanent Hardness

Permanent hardness is commonly caused by the sulphates, chlorides and nitrates of calcium and magnesium. Treatment of the water with lime and/or commercial soda as shown in the following equations is a method which may be applied to remove the hardness.

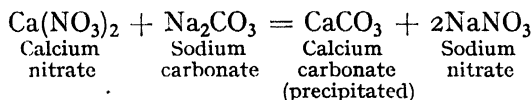
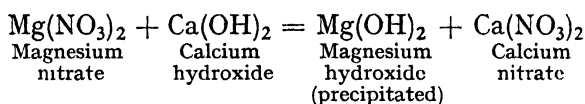
Combined treatment to render magnesium sulphate harmless:



Combined treatment to render magnesium chloride harmless:

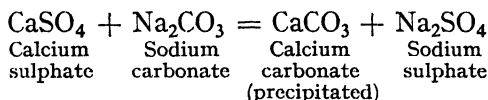
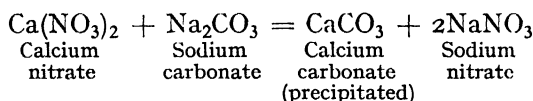
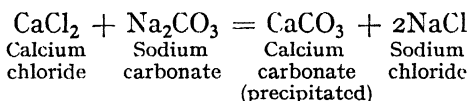


Treatment to render magnesium nitrate harmless:



In the above equations it will be seen that a sodium salt is left in solution in each case. These salts are harmless but may be removed by blowing-down the boilers. This treatment reduces the salinity of the water.

Calcium impurities are treated by the addition of commercial soda only:



The sodium salts left in solution are treated as stated before by "blowing-down."

THE WATER-SOFTENING PLANT

A water-softening plant of the Kennicott type is shown in Fig. 162a. The reagent is added to the water by means of the lift-pipe method (Fig. 162b). The hard water from the supply enters the plant and is divided at an adjustable weir. Only a small portion is diverted to the regulator tank whilst the main part of the supply water passes on to a water wheel which is used to operate the stirring mechanism in the reagent tank. From the water wheel the water enters the reaction tank and mixes with the reagent. Then the water is passed on to the filter beds and thence to the boiler plant.

The reagent tank (Fig. 162b) holds a definite amount of reagent, i.e. lime or soda or a mixture of the two which is dissolved in water. When the regulator tank is full of water, the

reagent tank is empty. At this stage the main supply of water which has entered the plant has been treated with the correct amount of reagent. But when the regulator tank is nearly empty

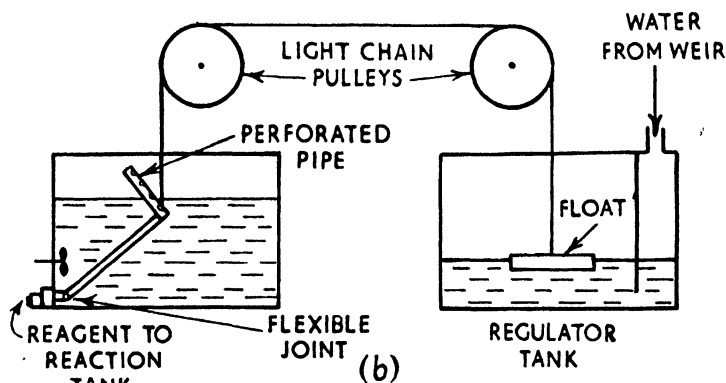
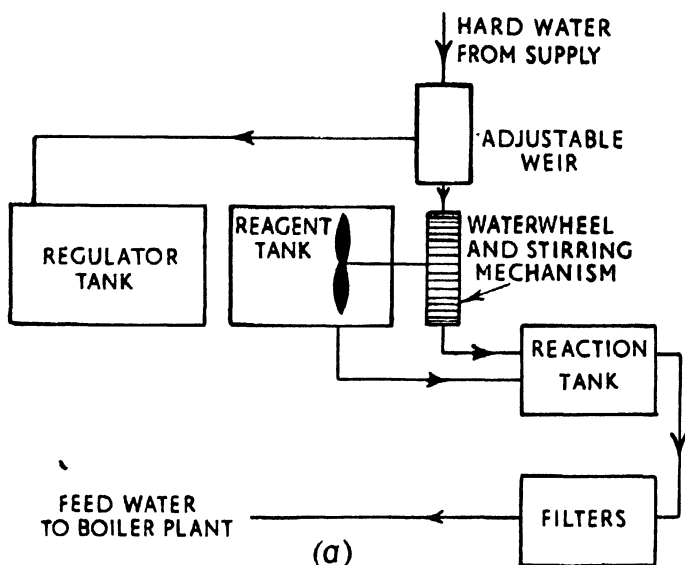


FIG. 162

the reagent tank is nearly full of reagent. The supply of reagent to the reaction tank is controlled by the float in the regulator tank, which in turn is controlled by the rate of flow of water passing into the regulator tank from the adjustable weir.

EXERCISES

1. Give an account of the impurities occurring most frequently in mine waters. Explain, briefly, what you understand by the terms "hard" and "soft" in relation to water. How may one kind of hardness be removed from water? (Min. Sc.; U.L.C.I.)

2. 100 lb. of limestone containing 95 per cent. of calcium carbonate are heated in a lime kiln and converted to quicklime. Calculate the weight (in lb.) of carbon dioxide evolved. (Atomic weights: C=12, Ca=40, O=16.) (Min. Sc.; U.L.C.I.)

3. Outline the methods by means of which you could test the suitability of a natural water for use in a boiler. What treatment would be necessary in the case of hard water? (Min. Sc.; U.L.C.I.)

4. One gram of coal when completely burned in oxygen gave 2.64 grams of carbon dioxide. Calculate the percentage of carbon in the coal. (Atomic weights: C=12, O=16.) (Min. Sc.; U.L.C.I.)

5. Give an account of the impurities present in mine waters. How can the temporary and permanent hardness be removed from water? (Min. Sc.; U.L.C.I.)

6. Ten grams of carbon are burned in an unlimited supply of air. What is the name of the compound obtained, and what is its weight in grams? (Atomic weights: C=12, O=16.) (Min. Sc.; U.L.C.I.)

7. 100 lb. of coal containing 90 per cent. of carbon are burned in excess of air. Calculate the weight (in pounds) of carbon dioxide produced. (Atomic weights: C=12, O=16.) (Min. Sc.; U.L.C.I.)

8. Define the terms "element" and "compound." Name six of each met with in coalmining, and describe briefly their properties from the miner's point of view. (Min. Sc.; U.L.C.I.)

9. Give one example to illustrate the use of each of the following terms, choosing, as far as possible, examples which may be met with in mining: element, compound, acid, salt, chemical reaction, oxidation. (Min. Sc.; U.L.C.I.)

CHAPTER XX

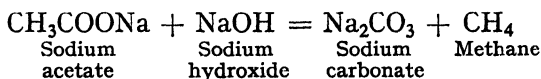
MINE GASES AND EXPLOSIONS

MINE GASES

The gases oxygen, nitrogen and carbon dioxide which constitute ordinary air have already been discussed in Chapter XVII. Mine air consists of these gases, not quite in the same proportions as in ordinary air, but mixed with other gases produced by various causes underground. These additional gases are mainly methane, carbon monoxide and hydrogen sulphide, while carbon dioxide usually exists in greater proportions than in ordinary air. Pure methane rarely occurs in mines, but when existing in percentages by volume of 60 to 100 with varying percentages of oxygen, nitrogen and carbon dioxide, it is known as firedamp. Carbon monoxide and hydrogen sulphide are known as whitedamp and stinkdamp respectively and the term blackdamp refers to mixtures of carbon dioxide with nitrogen, etc.

Methane

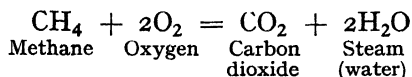
Methane is prepared in the laboratory by heating to a high temperature a mixture of one part of sodium acetate and two parts of caustic soda (sodium hydroxide) in a hard glass tube, provided with a cork which is fitted with a delivery tube (Fig. 163). A quantity of quicklime assists in the reaction and is unaltered at the end. The methane is collected over water and the chemical reaction is shown below:



Properties of Methane

Methane is a colourless, odourless, tasteless and non-poisonous gas. If lime water is added to methane, the lime water is unaffected. When a light is applied to the mouth of a jar containing methane, the gas burns with a non-luminous flame. Then on adding lime water to the jar and shaking, the lime water assumes a milky appearance, showing the presence of

carbon dioxide. The burning of the methane is shown by the following reaction:



Methane is a lighter gas than air in so far as it can be poured upwards from one jar to another. If a light is applied to the upper jar, the contained gas burns, showing that the methane has displaced the air. Drops of water are formed on the sides of the jar in accordance with the equation shown above. The

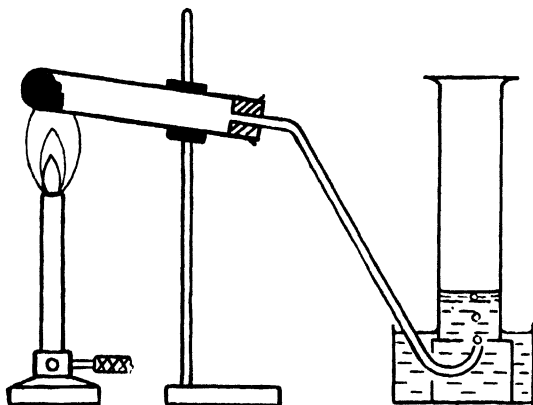
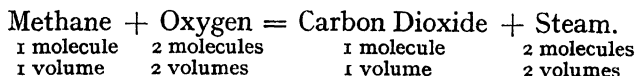


FIG. 163

fact that methane is lighter than air is very important from the point of view of mining.

When methane and air are mixed in certain proportions and a flame is applied, the mixture explodes. In the above equation which represents the burning of methane we have:



When the steam condenses to water, this is equivalent to three volumes of the mixture producing one volume of carbon dioxide. The outrush during a methane explosion due to the increase in the volume of the gases at the high temperature and then the inrush (after-blast) due to the partial vacuum formed by the condensation of the steam can now be understood.

Ignition Temperature

The ignition temperature of a substance is the temperature at which the substance begins to burn.

EXPLOSIONS

When ordinary coal gas is burned at a jet the supply of gas is controlled, i.e. the rate at which the gas is allowed to come into contact with the air is slow and regular and the flame cannot spread. If a large quantity of coal gas is allowed to escape into a room, under certain conditions, a light applied to the mixture of gas and air results in an explosion. This is due to the burning of the whole quantity of coal gas at once. The flame, once started, spreads instantaneously.

Similarly if hydrogen is burned at a jet, the burning is orderly. But if hydrogen and oxygen are mixed in certain proportions, and the mixture is ignited, the flame spreads and cannot be controlled. If the hydrogen and oxygen are mixed in the proportion of 2 to 1 by volume, the explosion has its maximum force.

Methane, like coal gas and hydrogen, can be burned at a jet in a controlled manner without an explosion taking place. But if the methane and air are mixed in certain proportions by volume, and a small quantity of the methane is ignited, the flame spreads suddenly and the result is an explosion. Evidently the flame once started cannot be controlled.

During an explosion the gaseous products are at a very high temperature. This tends to cause a great increase in volume and, since there is opposition from the surrounding air, the pressure increases suddenly. The effect is more marked in the case of explosive liquids owing to the greater increase in the volume of the gaseous products of combustion compared with the volume of the liquid.

If steam is one of the products of combustion, when the steam condenses, a partial vacuum is formed which, as we have seen, is the cause of the after-blast in methane explosions.

Explosive and Non-Explosive Mixtures of Methane and Air

Tests have been made on the explosibility of mixtures consisting of various percentages of methane in air and the following results have been obtained. If the quantity of methane in the air is less than 5.6 per cent. by volume, the applied flame simply causes the methane to burn near the flame, but with increasing percentages of methane up to 5.6 per cent. the

volume of the burning space increases. For 5·6 per cent. of methane in the air, a flame just passes silently through the mixture even when the source of ignition is removed. With increasing percentages of methane above 5·6, a weak explosion occurs, which gradually increases in intensity until the percentage becomes 9·4. In this case the explosion is most violent. As the percentage of methane increases from 9·4 to 15, the violence of the explosion diminishes, until at 15 per cent. the flame simply passes silently through the mixture. Then for higher percentages, the methane again burns near the applied flame, until at 25 per cent. the methane ceases to burn.

From the above it can be seen that for percentages of methane in air from 5·6 to 15 the mixtures are inflammable, 5·6 being the lower limit of inflammability and 15 per cent. the upper limit. (N.B. The above percentages are only approximate.)

Thus we may define an inflammable mixture as one through which a flame travels independently away from the source of ignition.

In the above tests the spark from an electric arc is a more convenient and safer method of ignition.

FIRE DAMP

Methane is a naturally occurring gas which may be found in variable quantities during the working of certain seams. This gas is often known as firedamp. Firedamp, however, is not pure methane, but consists of a mixture of various gases, the greatest percentage being methane, viz. 60 to 100 per cent. methane with varying amounts of oxygen, nitrogen and carbon dioxide.

Deeper seams of coal are usually associated with a higher firedamp emission than more shallow seams. This feature is due to the fact that gases may escape more easily from shallow seams to the surface by means of faults, joints and other passages. Firedamp is generally found in cavities and caunches as well as in rise headings or roadways. The production of firedamp during the working of a particular seam may be reduced by improving the method of roof support on the face. This prevents crushing of the coal and minimises the emission of the gas.

Detection of Firedamp—Estimation of Methane Percentage by Caps

The structure of a bunsen flame burning in air has already been discussed in Chapter XVII. What is the structure of a flame which burns in a mixture of methane and air?

The flame safety lamp is supplied by oil and when the lamp

is introduced into a mixture of methane and air containing less than 5.6 per cent of methane, a pale blue "cap" is formed at the top of the flame. If the original flame is lowered so as to possess no luminosity, this blue cap can easily be seen. The cap is caused by the ignition of the methane particles near the flame, the ignition temperature of methane being 700° C. approximately. The heat produced by the burning methane particles is transmitted by convection currents to the adjacent methane particles and these ignite and so on. But since the initial source of heat is limited and much of the heat has to be used in raising the temperature of the particles of air, the cap

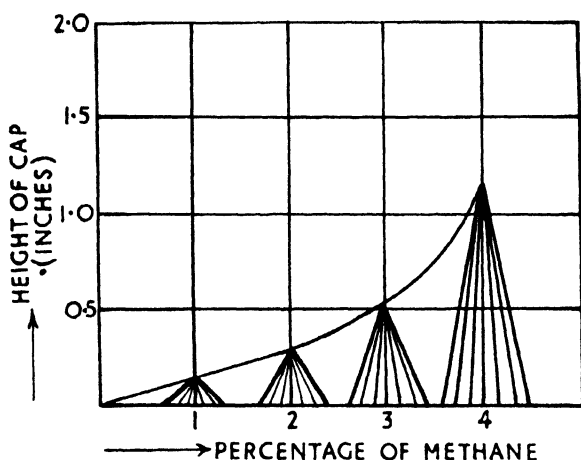


FIG. 164

extends only a limited distance, for beyond this distance the particles of methane do not reach their ignition temperature. If a greater concentration of methane particles is present, i.e. if the methane particles are nearer together, less air particles are present for absorbing the heat. Thus more heat is available for raising the temperature of the methane particles to the ignition point and the cap spreads farther. It would seem, therefore, that the height of the cap is in some way connected with the concentration of the methane particles, and if we use a flame of standard size and heating value, the height of the cap is an approximate measure of the percentage of methane in mine air.

The graph (Fig. 164) shows the relation between the height of the cap and the percentage of methane present.

Flame safety lamps are generally constructed on the "protector" pattern, which possesses an arrangement for raising or lowering the flame. The lamp has two gauzes as a safety precaution in the event of the inner gauze being defective. If the lamp is taken into an area where the percentage of methane is above the lower limit of inflammability the height of the flame increases too much and the lamp is withdrawn from the danger zone.

For normal testing purposes the flame is adjusted until it is almost non-luminous. Then the cap will form according to the percentage of methane present.

The estimation of the percentage of methane in mine air by means of caps is very important from the point of view of safety in mines. In the first place it is important to remember that the Coal Mines Act gives certain statutory limits with regard to the percentage of inflammable gas, i.e. methane, present. Men are withdrawn from the face when the percentage of inflammable gas in the general body of the air is 2.5 and electrical machinery is cut off when mine air contains 1.25 per cent. of inflammable gas.

BLACKDAMP

Carbon dioxide has already been discussed in Chapter XVII. Blackdamp is a mixture of carbon dioxide, nitrogen and oxygen, the carbon dioxide being present in percentages ranging from 5 to 20 per cent. The nitrogen is merely the residual nitrogen of the air, the oxygen of which has been partially or wholly converted into carbon dioxide.

Blackdamp is produced by the liberation of naturally formed carbon dioxide from the strata into the mine atmosphere and, as we have seen, when the oxygen of the air is replaced by carbon dioxide due to oxidation. In mines where the use of naked lights is permitted a direct estimation of the percentage of carbon dioxide present can be made by means of the Haldane tube.

Extinctive and Irrespirable Atmospheres

When phosphorus burns in air in a confined space the whole of the oxygen in the space is used up, provided there is sufficient phosphorus present. In the case of a candle burning in air in a small air-tight gas jar, the flame is extinguished long before all the oxygen is used up and an extinctive atmosphere is produced. Thus we may define an extinctive atmosphere as one which does not support combustion.

On the other hand, when the oxygen in an atmosphere is deficient in quantity, breathing is very difficult and when the percentage of oxygen is low enough the atmosphere will not support life. An atmosphere which will not support life is known as an irrespirable atmosphere. Both these types of atmosphere may be found in underground workings after an explosion or a fire and may also be produced by an accumulation of gases such as firedamp or blackdamp.

In all cases the atmosphere formed is deficient in oxygen due either to replacement by oxidation or by the presence of other gases. If the quantity of oxygen is not more than 17.9 per cent. by volume, a flame is readily extinguished and under these conditions no atmosphere should be entered. An atmosphere containing less than 11 per cent. of oxygen by volume will not support life. The effect of various percentages of carbon dioxide in mine air on an oil flame and on human beings is shown in the following table.

Normal breathing	N (79 per cent.)	O (21 per cent.)		
Deeper breathing	N (79 per cent.)	O (20.4 per cent.)		No effect on flame
Panting	N (79 per cent.)	O (20 per cent.)	1%	Dull flame
Increased panting	N (79 per cent.)	O (19 per cent.)	CO ₂ 2%	Dull smoky flame
Excessive panting	N (79 per cent.)	O (18 per cent.)	CO ₂ 3%	Flame extinguished
Severe distress	N (79 per cent.)	O (16 per cent.)	CO ₂ 5%	
Death	N (79 per cent.)	O (11 per cent.)	CO ₂ (10%)	

Estimation of the Percentage of Carbon Dioxide by Volume in a Mine Air Sample

The percentage of carbon dioxide in a sample of mine air is determined by means of the Haldane Apparatus (Fig. 165). The sample is passed into an absorption pipette, containing caustic potash solution, which absorbs the carbon dioxide present. If the volume of the sample is measured before and after introduction to the pipette the reduction in volume due to absorbed carbon dioxide may be measured and the percentage of carbon dioxide in the sample calculated.

The diagram indicates the arrangement of the apparatus.

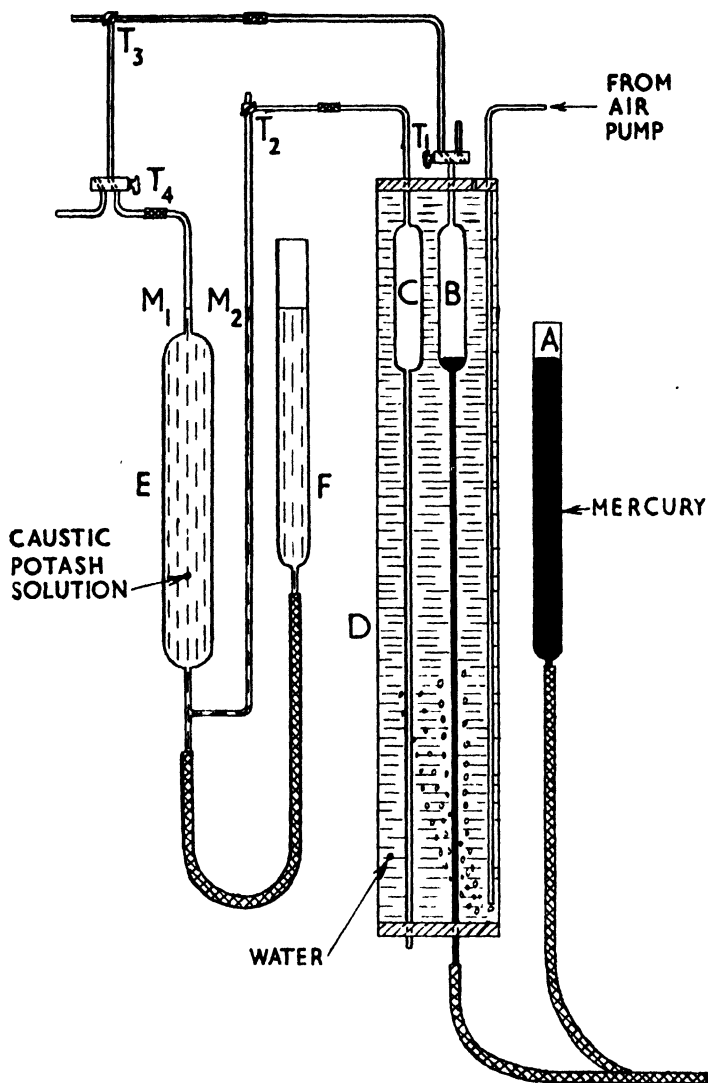


FIG. 165

The movement of the mercury reservoir A in conjunction with the two-way tap T_1 is used to draw in or expel the mine air sample to or from the graduated burette B. The absorption pipette E contains a solution of caustic potash, the level of which is regulated by the reservoir F, while the burette C which is

exactly similar to B is used solely for the purpose of compensating for changes of temperature and pressure.

The taps T_2 , T_3 and T_4 are opened to the atmosphere and the reservoir F is adjusted in such a manner that the caustic potash solution is brought up to the mark M_2 . The taps T_1 , T_3 and T_4 are then placed in communication with the pipette E and the reservoir A is adjusted to bring the level of the caustic potash solution to the mark M_1 . T_1 , T_3 and T_4 are then closed. The two-way tap T_1 is opened to the atmosphere and the air is expelled from the graduated gas burette B, by raising the mercury reservoir A. The bladder containing the mine air sample is then connected to the tap T_1 and a sample of the air is drawn into the burette B by lowering the reservoir A, the volume being read by means of the graduations.

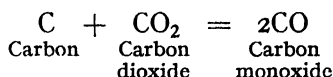
The taps T_1 , T_3 and T_4 are then adjusted to put the burette B in communication with the pipette E. The reservoir A is raised and the air sample is forced out of the burette B into the pipette E, where it comes into contact with the caustic potash solution. After the air sample has been in contact with the caustic potash solution for several minutes the reservoir A is lowered and the sample is drawn back into the burette B. When the caustic potash solution reaches the marks M_1 and M_2 , the volume of the sample is read by means of the graduated burette B.

The sample is again passed over to the pipette E, and the previous operations are repeated. If there is no change in volume, it may be taken that all the carbon dioxide was absorbed in the previous operation. The reduction in volume is determined and this is expressed as a percentage of the initial volume of the sample.

CARBON MONOXIDE

Reduction of Carbon Dioxide to Carbon Monoxide by Red-hot Carbon

Carbon dioxide is generated in the bottle A (Fig. 166) by the action of dilute hydrochloric acid on marble chips and it is passed over red-hot carbon in the iron tube B. The carbon dioxide gas is reduced to carbon monoxide according to the following reaction:



The carbon monoxide along with any carbon dioxide which

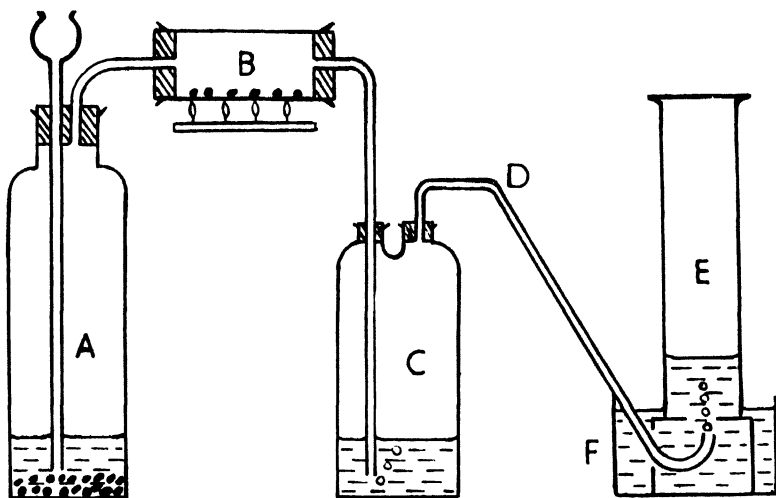


FIG. 166

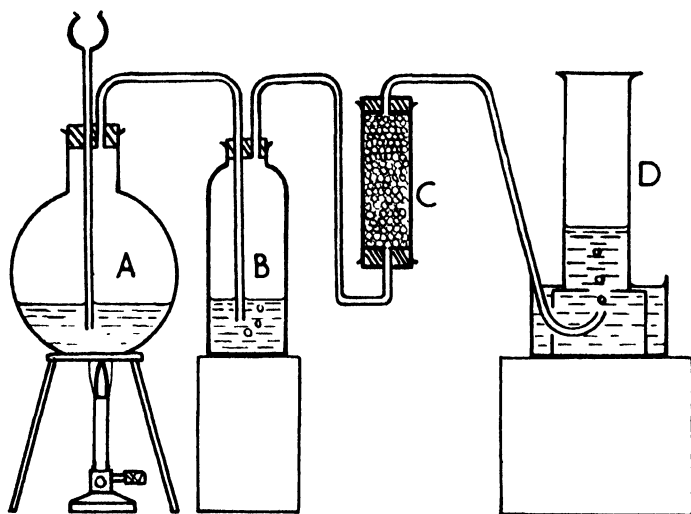
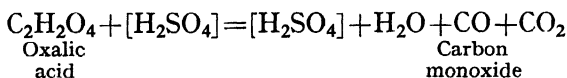


FIG. 167

has not been reduced is bubbled through caustic soda solution in the bottle C. The carbon dioxide gas is absorbed while the carbon monoxide proceeds through the delivery tube D and is collected over water in the vessel E which stands on a beehive shelf, in the trough F.

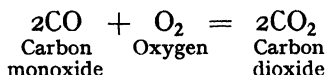
Preparation of Carbon Monoxide Gas

Carbon monoxide can be prepared in the laboratory by the action of strong sulphuric acid on oxalic acid. The flask A contains oxalic acid and strong sulphuric acid is poured down the thistle funnel into the flask (Fig. 167). A mixture of carbon dioxide and carbon monoxide is produced and the sulphuric acid simply absorbs the water from the oxalic acid. The two gases produced are passed through the bottle B which contains caustic soda solution and the carbon dioxide is absorbed. The carbon monoxide, together with any trace of carbon dioxide, is passed through the bottle C, which contains solid caustic soda in small pieces, and any carbon dioxide is absorbed. The pure carbon monoxide is then collected over water in the jar D. The chemical reaction is represented as follows:



Properties of Carbon Monoxide

Carbon monoxide is an odourless, colourless and tasteless gas which is only slightly soluble in water. When a light is applied to the mouth of a gas-jar containing carbon monoxide, the gas burns with a bluish flame. If lime water be added to the jar, after shaking, the lime water assumes a milky appearance. Evidently the burning of carbon monoxide produces carbon dioxide, viz.:



Occurrence of Carbon Monoxide in Mines

We have already seen how carbon dioxide is reduced by red-hot carbon to carbon monoxide. A similar process takes place in underground fires. Any carbon dioxide produced by the combustion of the carbon in the coal passes over red-hot coal and is reduced to carbon monoxide. In effect, when carbon burns in a limited supply of oxygen, carbon monoxide is produced.

Carbon monoxide may be detected in the mine by its effect on warm-blooded animals such as mice, birds, etc. The percentage of carbon monoxide in mine air may be estimated by the analysis of mine air samples.

Physiological Effects of Carbon Monoxide

The effect of carbon monoxide on human beings can be very serious. In the absence of carbon monoxide, the hæmoglobin of the blood absorbs oxygen. But if carbon monoxide is present, the affinity of the hæmoglobin for the carbon monoxide is greater than its affinity for oxygen and a compound known as carboxy-hæmoglobin is formed. Under these conditions the blood ultimately loses its affinity for oxygen and the miner suffers from carbon monoxide poisoning.

Experiments show that the extent of carbon monoxide poisoning depends on the amount of gas present, the length of time the miner is exposed to the gas and the physical condition of the miner. Much work has been done by the Safety in Mines Research Board to protect the miner from carbon monoxide poisoning.

Small warm-blooded animals are affected by carbon monoxide poisoning in a much smaller time than human beings, and to test for the presence of carbon monoxide, a mouse or a linnet is exposed to the gas in a cage which allows free movement.

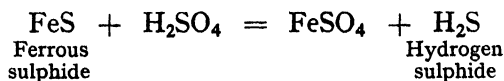
HYDROGEN SULPHIDE

Occurrence

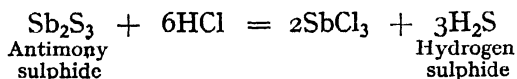
Hydrogen sulphide, or sulphuretted hydrogen as it is commonly called, is liberated during the decay of animal and vegetable matter containing sulphur. The formation of the gas is due to bacterial action.

Preparation

The apparatus used for preparing hydrogen sulphide is shown in Fig. 168. Iron sulphide in small pieces is placed in the bottle A and dilute sulphuric acid (1 part of acid and 7 parts of water) is poured down the funnel. The gas evolved is washed in the bottle B which contains water and it is then collected in the jar C. The chemical reaction is given below:



Hydrogen sulphide in the pure state is produced by the action of hydrochloric acid on antimony sulphide, thus:



Properties

Hydrogen sulphide is a colourless gas with an offensive smell like that of bad eggs. It is poisonous in its pure state but even when diluted it gives dizziness and headache. Some animals are more affected by the gas than others.

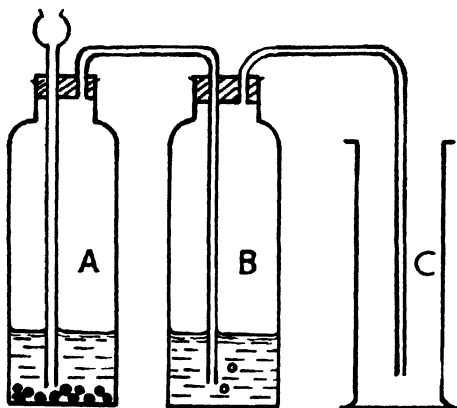
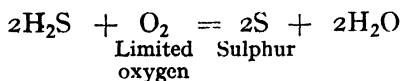
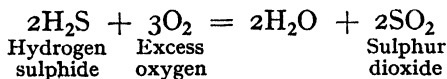


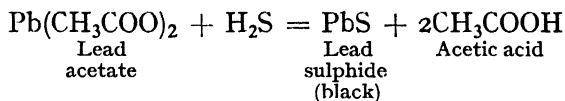
FIG. 168

Hydrogen sulphide is soluble in cold water, so that in its preparation the water in B (Fig. 168) must be warm. A solution of hydrogen sulphide in water has a slight acid reaction with blue litmus and quickly decomposes in air. The hydrogen of the hydrogen sulphide combines with the oxygen of the air and the liquid becomes contaminated with a precipitate of sulphur. Hydrogen sulphide is inflammable and burns with a bluish flame according to the following reactions:



Detection of Hydrogen Sulphide

A filter paper moistened with lead acetate is turned black by the action of hydrogen sulphide upon it. The chemical reaction is shown below:



COAL DUST EXPLOSIONS

Explosions of mixtures of methane and air have already been discussed. These are not the only types of explosion which take place in mines. Explosions of coal dust may occur even though methane is absent, and an explosion will take place if the following conditions exist: (1) A flame is brought into the dust suspension at a sufficiently high temperature, (2) oxygen or air is present in sufficient quantity, (3) the coal dust is in fine suspension, (4) the density of suspension is such that the particles of coal dust are near enough together to allow the heat produced in the combustion of the particles at the source of ignition to ignite the adjacent particles and so on.

In dealing with mixtures of methane and air we have already seen that an explosion is an uncontrolled flame which spreads with great rapidity through the mixture. In the same manner the fine particles of coal dust, under the above conditions, burst into flame on reaching their ignition temperature and the flame spreads rapidly through the whole of the dust. The heat developed causes the air in the explosion area to expand suddenly against the resisting pressure of the surrounding air and in this way tremendous pressures are set up.

Coal dust explosions may be caused by local explosions of firedamp, during shot-firing operations or by an open flame such as an electric arc. It is therefore essential to guard against these possible sources of ignition by observing C.M.A. regulations concerning ventilation, use of explosives and use of electricity.

The spreading of incombustible dust in mine workings is a method widely adopted to render coal dust harmless. Thus if a few particles of coal dust become ignited some of the heat produced is absorbed by the stone dust which if present in sufficient quantity leaves insufficient heat to ignite the adjacent coal dust particles. The C.M.A., 1911, and general regulations provided certain specifications regarding the spreading of incombustible dust and the use of water for consolidating the coal dust.

Water is often used to prevent the formation of clouds of coal dust. This is done by using sprays at loading points, at conveyor transfer points, at intervals along haulage roads, on drilling machines and on coal-cutters. In such a manner the production and subsequent spreading of coal dust may be considerably reduced, thus lessening the risk of explosions.

SPONTANEOUS COMBUSTION

During the slow oxidation of a substance all the heat developed may be carried away by conduction, convection, etc., and the temperature of the substance remains constant. But in the case of substances which oxidise rapidly the heat is produced at such a rate that it cannot be carried away quickly enough and the temperature of the substance is raised. This process continues, with increased oxidation, until the ignition temperature is reached, when the substance begins to burn and the amount of heat is then sufficient to maintain the temperature of the substance above its ignition point. If, in the oxidation of a substance, the heat developed is insufficient to raise the temperature to its ignition point, the substance cannot ignite and spontaneous combustion cannot take place.

There are various factors which assist the spontaneous combustion of a substance. As there is no applied source of ignition, the substance must oxidise very readily. Also the heat developed in the oxidation of the substance must not be readily conducted away, and hence the substance must be surrounded by poor thermal conductors. A low ignition temperature is another factor which aids the initial burning of the substance and also a plentiful supply of oxygen is required for the combustion to continue. But air currents must not be strong enough to carry away the heat developed in the combustion. Lastly, the area exposed to oxidation must be as large as possible and this condition is satisfied if the material is in a finely divided state.

The Spontaneous Combustion of Coal

It is found that some coals combine with oxygen from the air more readily than others. This combination gives rise to an increase in temperature, especially if the air-flow is slow, and if oxidation is allowed to continue it will increase in tempo with rise in temperature, until the ignition temperature of the coal is reached.

In mines liable to spontaneous combustion the method by which the coal is worked should be chosen carefully, and

during working strict supervision should be enforced. A sufficient supply of fire-fighting material, e.g. stone dust, sand, water and fire-extinguishers, should be kept readily available.

Spontaneous combustion may be aided by the oxidation of materials such as timber, brattice and pyrites. In the long wall system of mining care should be taken to prevent such materials or coal as far as possible from being left in the packs or wastes.

EXERCISES

1. Give an account of the occurrence, preparation and properties of methane. Describe how the presence of firedamp in coal mines may be detected by means of gas caps. (Min. Sc.; U.L.C.I.)
2. Describe the chief properties of sulphur. What substances found in coal mines contain sulphur? How may stinkdamp be detected in mines? (Min. Sc.; U.L.C.I.)
3. What are the chief causes of colliery explosions? What factors affect the explosibility of coal dust? (Min. Sc.; U.L.C.I.)
4. Describe the preparation and properties of carbon monoxide. How do you account for the production of carbon monoxide in coal mines? Describe an experiment to explain the occurrence of whitedamp at underground fires. (Min. Sc.; U.L.C.I.)
5. Describe the preparation and properties of hydrogen sulphide. What are the sources of "stinkdamp" in coal mines, and what tests are used for its detection? (Min. Sc.; U.L.C.I.)
6. Describe the preparation and properties of methane. How do you account for the presence of "firedamp" in coal mines, and how would you carry out tests for its detection in the workings of a mine? (Min. Sc.; U.L.C.I.)
7. What is meant by the term "spontaneous combustion"? Describe how a "gob fire" might start, and some simple precautions which would reduce the probability of such occurrences. (Min. Sc.; U.L.C.I.)
8. How should you test for firedamp in the pit? Make a sketch of the "cap" you would expect to find when 3 per cent. of firedamp was present in the mine air. What is the smallest percentage of firedamp which, when mixed with air, will form an explosive atmosphere? (Min. Sc.; U.L.C.I.)
9. Explain how a coal dust explosion differs from a firedamp explosion. What gases would you expect to find in the atmosphere (a) after a firedamp explosion, and (b) after a coal dust explosion. (Min. Sc.; U.L.C.I.)
10. Mention three substances which burn in air and three which do not burn. How are substances which do not burn used in mines (a) to prevent explosions, and (b) to put out fires? Explain their action in each of the cases you mention. (Min. Sc.; U.L.C.I.)
11. What percentages of firedamp in a mine do you consider to be dangerous and what percentage is explosive? Where in the mine is firedamp most likely to be easily detected? (Min. Sc.; U.L.C.I.)

12. Describe in detail, sketching the apparatus required, how you would prepare methane. How do you account for the presence of methane in coal mines? How would you estimate the percentage of firedamp at the ripping lip in a drawing road of a coal mine by means of a flame safety lamp? (Min. Sc.; U.L.C.I.)

13. How would you determine the percentage of methane and carbon dioxide in a given sample of mine air? (Min. Sc.; U.L.C.I.)

14. What are the chief gaseous products of the combustion of coal in air? Describe briefly their properties. (Min. Sc.; U.L.C.I.)

15. State the main properties of firedamp. What are the chief causes of explosions in mines and what precautions are taken to prevent them? (Min. Sc.; U.E.I.)

16. Describe fully what you understand by the chemical equation: $\text{CO}_2 + \text{C} = 2\text{CO}$. What experiment would you perform to illustrate the reaction shown by the equation? Explain the importance of this reaction. (Min. Sc.; U.L.C.I.)

17. Describe how each of the oxides of carbon may arise in mine atmospheres. State how you would detect their presence, and compare their physiological effects. (Min. Sc.; U.L.C.I.)

18. Give a general account of the physiological effects of the presence of (a) carbon monoxide, (b) firedamp, and (c) moisture in mine air. (Min. Sc.; U.L.C.I.)

19. Describe the properties of methane and carbon monoxide and explain how they are detected. (Min. Sc.; U.L.C.I.)

20. How would you test for firedamp in the pit? State (a) the lowest percentage of firedamp in air, and (b) the highest percentage of firedamp in air that will form an explosive mixture. What is the most explosive mixture of firedamp and air? (Min. Sc.; U.L.C.I.)

21. Mention two frequent causes of colliery explosions and state what precautions are taken to avoid explosions due to these causes. (Min. Sc.; U.L.C.I.)

CHAPTER XXI

EXPLOSIVES

EXPLOSIVES

Explosives are used extensively in colliery work for the purpose of breaking down coal at the face as well as in caunch ripping, sinking and tunnel work. The use of explosives is regulated by the Coal Mines Act, 1911, and General Regulations. Due to these regulations many collieries may only use "Permitted explosives." Such explosives are permitted for use underground by the Ministry of Fuel and Power, after passing certain tests.

High and Low Explosives

Explosives are commonly referred to as "High" or "Low" explosives, this classification referring to the strength of the explosive. High explosives have a high rate of detonation due to the chemical combination of the fuel and the oxygen within the explosive material. This combination renders the oxygen more readily available and thus increases the rate of detonation. A typical example is nitro-glycerine.

Low explosives have a lower rate of detonation due to the fact that the fuel and the oxygen are provided by separate materials which are in a finely divided state and are mixed together to form the explosive material. In this case the oxygen is not as readily available during combustion and thus the rate of detonation is comparatively slow. Black powder or gunpowder, which consists of a mixture of charcoal, sulphur and potassium nitrate (saltpetre), is a typical low explosive. However, gunpowder is not included in the list of permitted explosives because of the danger of incomplete combustion which results in the formation of a hot residue, capable of igniting inflammable gas.

Sensitivity of an Explosive

The term sensitivity, as applied to an explosive, refers to its tendency to explode due to vibration, ignition, etc. Some explosives are more safely handled than others, the former being less sensitive than the latter.

Permitted Explosives

Permitted explosives have varying compositions which depend largely on the type of work for which they are designed. High and low explosives are used separately or combined in order to obtain the desired strength and sensitivity. Other materials with non-explosive properties, such as wood meal, sodium chloride or clay, are usually added for the purpose of altering the strength and sensitivity of the explosive.

High and low explosives such as nitro-glycerine and ammonium nitrate respectively are used in permitted explosives. Nitro-glycerine is very sensitive and may be mixed with ammonium nitrate which has a low sensitivity in order to produce an explosive of medium sensitivity. Materials such as nitro-cotton and tri-nitro-toluene may be added to nitro-glycerine to reduce its sensitivity and also to enable it to be handled more easily during manufacture.

Materials such as borax, hydrated salts, etc., are added to the explosives to act as cooling agents, whilst other materials are added to facilitate the process of cartridging. Sheathed explosives have a covering of sodium bicarbonate which acts as a cooling agent and also provides a protective cloud of carbon dioxide around the products of combustion.

Finally potassium nitrate or sodium nitrate is added with the object of supplying oxygen during combustion.

Permitted explosives may be divided into three classes: (a) ammonium nitrate explosives, (b) nitro-glycerine explosives and (c) explosives containing ammonium nitrate and nitro-glycerine.

Since ammonium nitrate explosives are not very sensitive, they usually contain some tri-nitro-toluene. Ammonium nitrate explosives are safer to handle and do not freeze as in the case of nitro-glycerine explosives. The explosives must be waterproofed as they are affected by moisture and should be carefully stored. The action of these explosives is not concentrated and they form a useful general-purpose explosive.

Nitro-glycerine explosives are very powerful and have a concentrated action, which makes them suitable for blasting tunnels in hard rock. These explosives have a good resistance to moisture but are susceptible to freezing. Careful storage should be arranged to prevent such occurrences.

Explosives containing ammonium nitrate and nitro-glycerine are used extensively in mining operations. The type of work for which they are designed is dependent on the percentage of

nitro-glycerine present in the explosive. The higher the percentage of nitro-glycerine the more suitable the explosive is for tunnel and ripping work. With smaller percentages of nitro-glycerine, the explosive may be used satisfactorily as a general-purpose explosive. Explosives suitable for coal usually contain only a small percentage of nitro-glycerine.

The choice of an explosive for mining work depends mainly on conditions, i.e. safety regulations which decide between the use of permitted and other explosives, the nature of the work

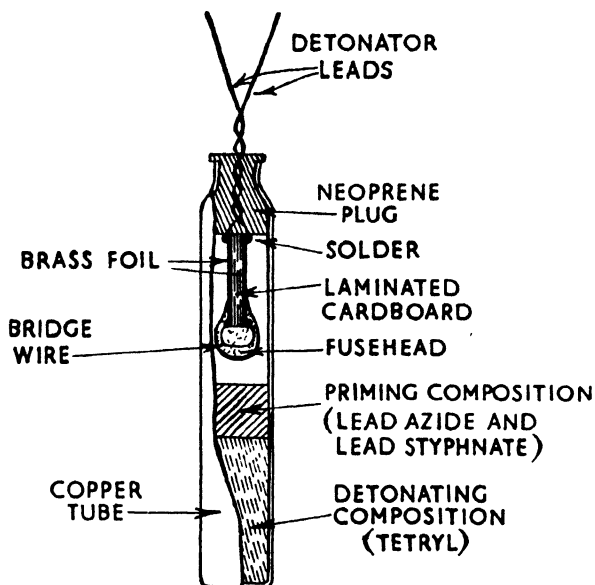


FIG. 169
(SECTIONAL VIEW)

to be done by the explosive and the natural conditions such as the presence of water.

DETONATORS

In underground work the use of electric detonators for igniting the explosive charges is common practice. These detonators are generally of two types, namely low-tension and high-tension.

The construction of high- and low-tension detonators is almost identical apart from the fusehead. In the low-tension detonator (Fig. 169) a bridge wire is used to ignite the fusehead

material, whilst in the high-tension detonator the introduction of carbon or other material in the fusehead mixture enables the mixture to pass a current and thus ignite itself.

Delayed-action detonators, which are becoming increasingly popular for certain classes of work, have already been discussed in Chapter XIII.

Production of Fumes when using Explosives

The use of explosives underground often gives rise to the production of fumes which have an irritating effect on the eyes and respiratory organs. The fumes consist largely of fine dust together with liquid in a fine suspension and also a variety of gases.

The liquid matter may be present in the form of nitrous or nitric acid in fine suspension, whereas the commonest gases formed are carbon dioxide, nitrogen, carbon monoxide, sulphuretted hydrogen, ammonia, nitrogen peroxide, nitrous oxide and nitrogen dioxide. Apart from the first two mentioned gases the remainder have poisonous properties, but they are present in such small percentages that they are not directly dangerous. Their effect, however, may be to cause a certain amount of discomfort due to irritation.

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